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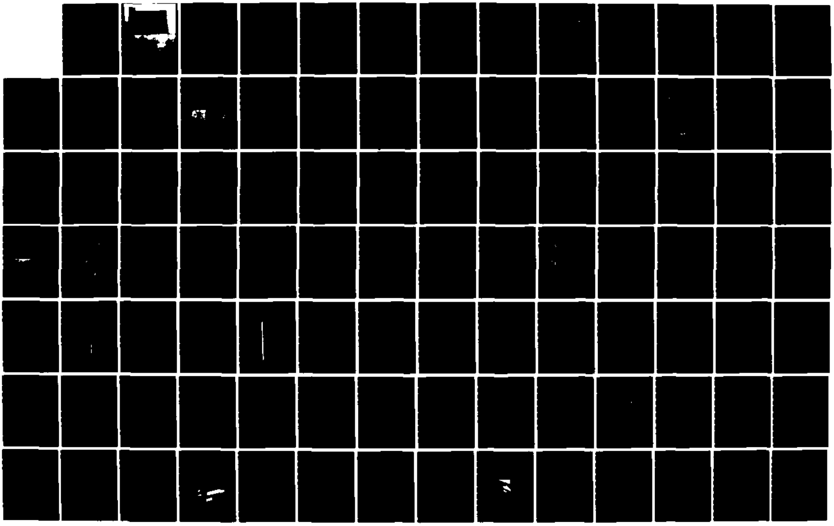

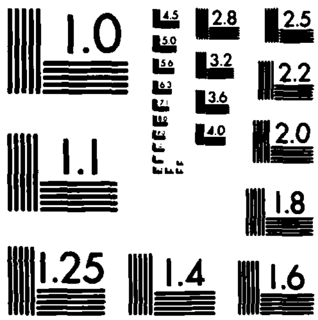

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DEPARTMENT OF OCEAN ENGINEERING
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASSACHUSETTS 02139

UTILITY OF THE M.I.T. UNDERWATER STUD WELDING GUN

by

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SM(NA&ME)

Course 13A
June 1984

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UTILITY OF THE M.I.T.

UNDERWATER STUD WELDING GUN

by

Henry Lowe Pruitt, Jr.

B.S.M.E., United States Naval Academy
(1978)

Submitted to the Department of Ocean Engineering
in Partial Fulfillment of the Requirements for the
Degree of

MASTER OF SCIENCE IN NAVAL ARCHITECHTURE AND MARINE ENGINEERING

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 1984

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May 23, 1984

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Accepted by ______________________
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Chairman, Departmental Graduate Committee

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ABSTRACT

A study was undertaken to determine tasks which could reasonably be undertaken by the M.I.T. underwater stud welding gun. During the study it was determined that many tasks either would require special apparatus, or the use of such apparatus would greatly reduce the ~~complicity~~ of the tasks, thereby reducing the required time as well as increasing the quality of the tasks performed. Lifting and turning padeye mounting, A-frame mounting, patching, marking, zinc replacement, hot tap mounting, shoring, cofferdam construction, jacking gear attachment, air lock attachment and space welding are the tasks that have been defined. Special templates, gaskets, gasket/templates, manipulator configurations, and pre-packaged stud welding "boxes" were designed to accomodate the defined tasks.

In order to appraise the utility of the underwater stud welding gun, special tasks and a means by which to evaluate the quality of the tasks performed have been selected. ~~It has been~~ hypothesized by the author that use of the M.I.T. underwater stud welding gun will not only reduce the time required to complete the selected tasks, but expand the environment of task accomplishment into conditions which presently are prohibitive.

Thesis Supervisor: Koichi Masubuchi

Title: Professor of Ocean Engineering & Materials Science

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Chapter 1

INTRODUCTION

1.1 Underwater Welding; State of the Art

As the petroleum industry has been forced farther and farther offshore into deeper and deeper waters in order to keep pace with the world's ever growing thirst for energy, welding technology has been challenged with the task of developing products, systems and processes that are capable of producing welds of structural integrity compatible with modern fabrication materials. In the past two decades, underwater welding, interest in which was only shared by navies and a few salvage companies, has become one of the essential elements in offshore exploration and development. In a short span of 25 years, underwater welding has exploded from an age when all the welding done was with stick electrodes dipped into either paraffin or varnish, or wrapped in electrical tape, to an era where several welding processes and automated welding systems enjoy utilization in an underwater environment [1].

Underwater welding is not without its problems. Though a great deal of work has been done to reduce the shortcomings caused by hydrogen embrittlement, reduction in toughness in the highly quenched heat affected zone, depth degradation of arc stability, and lack of consistent results, these problems persist. As a result, wet welding, as opposed to underwater dry welding in an underwater chamber or cofferdam, finds utilization in the bonding of components which require little or no structural integrity, or where the cost of an alternative method of joining critical components is staggering.(Figure 1.1 shows the different underwater welding processes)[18] Even though underwater welding is not utilized to its fullest potential, its critics are rampant. The U.S. Navy, for example, allows wet welds on its ships only in the case of an emergency and the work must be replaced by a dry weld at the first available opportunity. There is presently a ban on wet welding in the North Sea [2]. For this reason a method of performing wet welds capable of consistently producing mechanical properties comparable to those produced on the surface is needed.

1.2 Why a Stud Gun?

It is the opinion of the author that an underwater stud gun can best fullfill the requirement of consistently producing high quality welds in an undersea environment. This is because stud

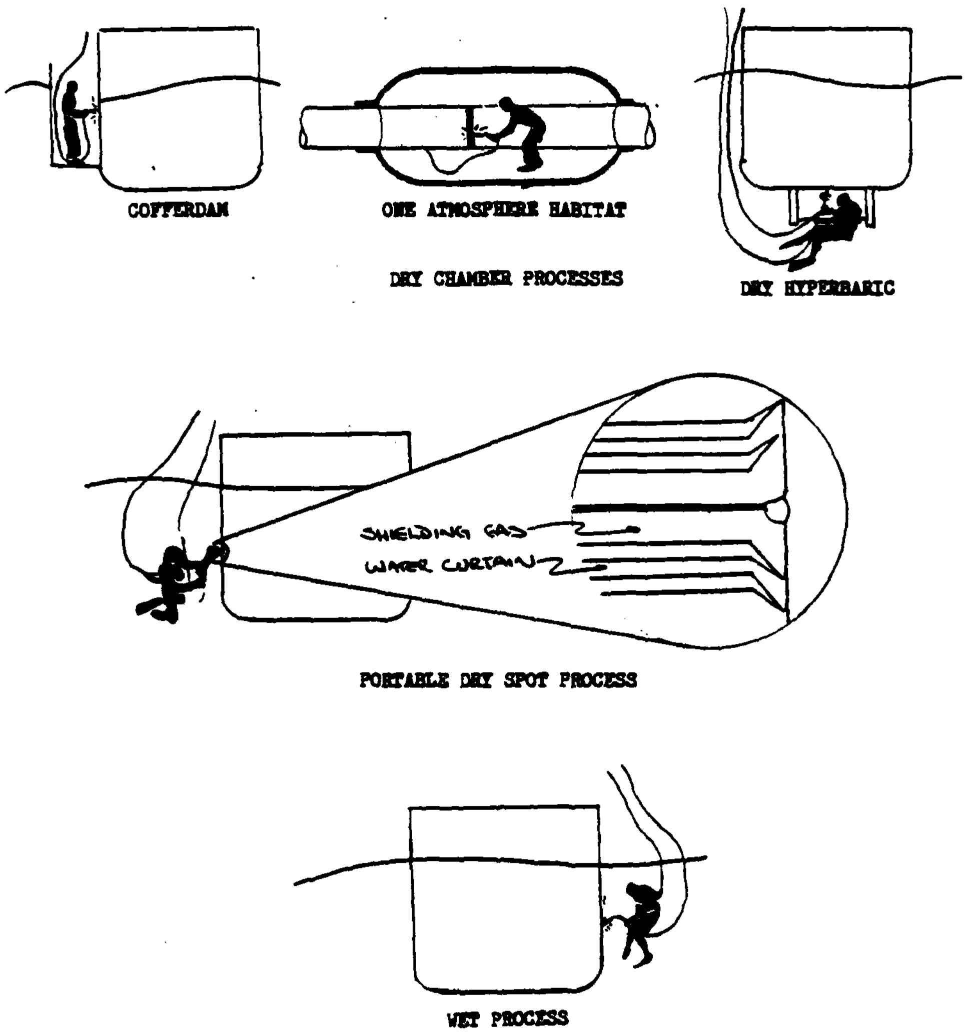


Figure 1.1 UNDERWATER WELDING PROCESSES

welding offers most of the flexibility of task utility of the shielded metal arc welding (SMAW) process while at the same time it is not as sensitive to the environment and operator skill.

The stud welding process basically consists of two steps [3].

1. Welding heat is provided by an arc between the stud and the base plate.
2. The stud is brought into direct contact with the base plate when the proper temperature is reached.

The basic equipment, consisting of a stud gun, DC power supply, control unit (timing device), cables, studs and ferrules, is diagramed in Figure 1.2. The mechanics of the stud welding process are illustrated in Figure 1.3.

Unlike a prepackaged system, such as the M.I.T circular patch welding package, a stud gun can be used for a myriad of tasks. Its performance is dependent upon the operator for proper geographical positioning, but not for the quality of its weld. Hence, stud welding inherently possess all the operator independence advantages of a prepackaged system. This gives stud welding an advantage over the SMAW process in that a stud welder needs no welding skills and the quality of the weld is not dependent upon his ability to consistently produce his best

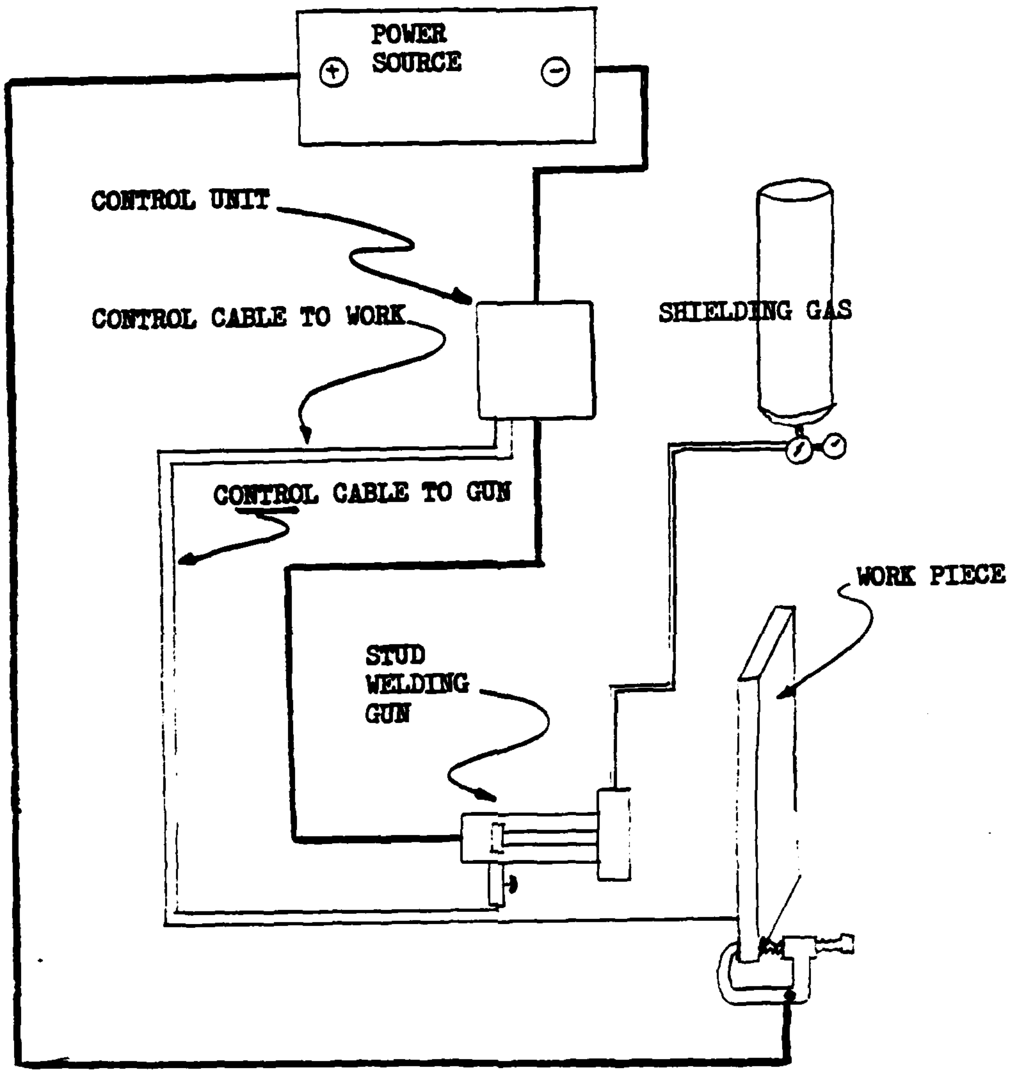
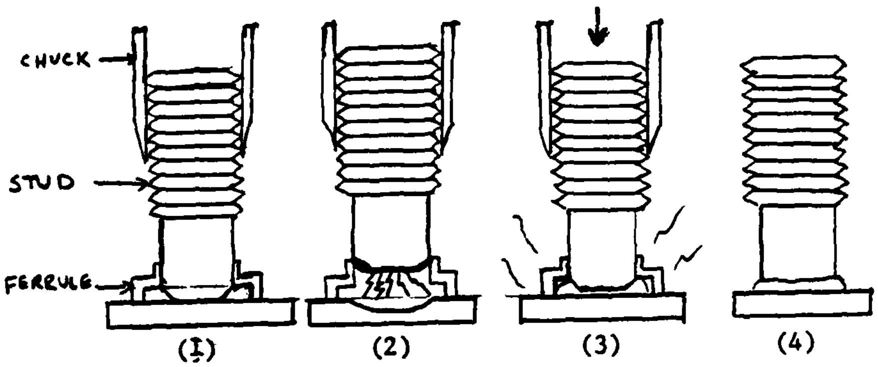


Figure 1.2 SCHEMATIC DIAGRAM OF STUD WELDING SYSTEM



Steps in stud welding: (1)Gun is positioned; (2) Trigger is pressed and stud is lifted, creating the arc; (3) arcing completed and stud pushed into molten pool of metal on the base metal; (4) Gun and ferrule are removed and stud is now welded.

Figure 1.3 MECHANICS OF ARC STUD WELDING [3] work. One can easily see the effects of welder fatigue, discomfort, position, obscured vision and lack of skill as well as undersea environmental phenomena like swell and current. While degrading the quality of SMAW welds, they will have no impact on the quality of underwater stud welds.

1.3 The M.I.T. Stud Welding Gun

Zanca [4] first developed a capacitor dicharge underwater stud welding gun. However his work did not investigate the effects of depth (pressure). He concluded that an underwater capacitive discharge stud welding process could be used, however its utility would be greatly limited, as studs of 1/4" diameter are the largest that can be used. In 1976 Chiba [5] performed tests on 3/4" and 1/2" diameter studs, in air and underwater (without the use of shielding gas). Chiba had difficulty initiating an arc consistently, thus, steel wool was required. His tests were performed at one atmosphere, thereby leaving the effects of depth unexamined.

Kataoka [6] investigated the effects of depth on wet and dry stud welds. He was able to eliminate the arc initiation problems encountered by Chiba, by ensuring the cable connectors and grounding clamps were secure. He concluded 3/4" studs could not be welded at depths due to arc bending and instability. As his work modeled conditions of totally wet or air shielded welds, this conclusion can be expected. Had he investigated the effects of using an argonox or heliox shielding gas, he may have had a different conclusion. At depth there are many adverse effects caused by nitrogen, not caused by helium and argon. Also small doses of oxygen 1-5% have been found to greatly improve weld quality at depth [7].

Schloerb [2] built a prototype welding gun and conducted several tests. His gun was large, difficult to use, and did not use a shielding gas. His gun did have a magnetic base that helped to maintain static position during welding. This base was also used to ground work pieces. The most recent work has been done by von Alt [8]. He has greatly improved the gun by making it smaller, easier to use, and by adding a shielding gas nozzle. (See Figure 1.4). Unfortunately, he has not used a magnetic grounding/holding device such as Schloerb. He also has developed a system by which welding parameters can be monitored, thus allowing engineers to judge the quality of welds as performed.

In the conventional stud welding of steel components, a small amount of flux permanently affixed to the end of the stud is used to deoxidize the weld metal and to stabilize the arc. Aluminum studs do not use the flux as helium or argon shielding

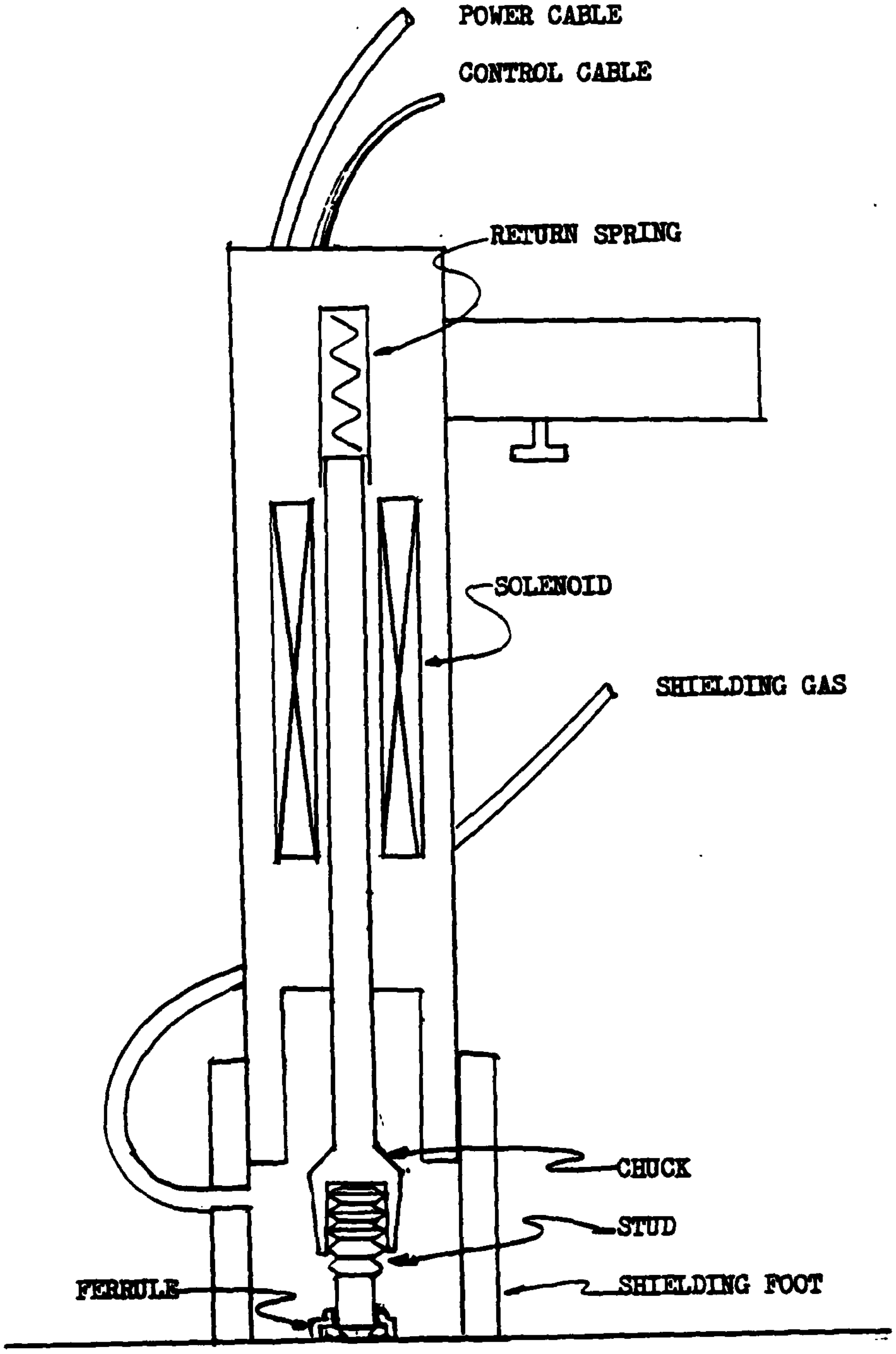


Figure 1.4 BASIC CONFIGURATION OF M.I.T. UNDERWATER STUD WELDING GUN

is required to serve this purpose [3]. Though the M.I.T. underwater stud welding gun has yet to demonstrate the capability of welding aluminum underwater, it uses a shielding gas for the welding of steel, as waterproofed fluxes have a very limited allowable exposure time to water, provide shielding less effectively and do not reduce the quenching rate as well as a shielding gas. From Figure 1.5 one can see that the shielding gas protects the weld more thoroughly than the flux.

The product at present is capable of producing welds, possessing properties approaching those of the stud and base plate in steel studs up to 3/4 inch diameter [6]. In order to find utility in the offshore industry, the stud welding system needs to have specific tasks defined and its performance capability demonstrated. Such is the purpose of this thesis.

1.4 Overview of the Thesis

Having discussed the state of the art, and the development of the M.I.T underwater stud weld gun, the author will now describe its capabilities and requirements in performing its most needed tasks.

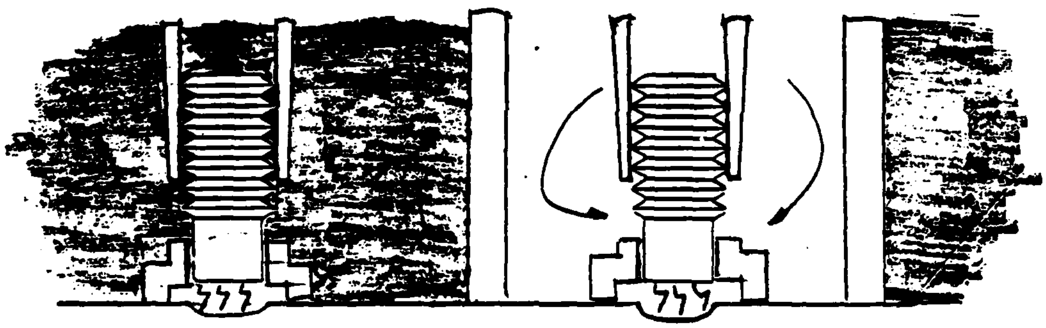


Figure 1.5 GAS SHIELDING vs. FLUX SHIELDING

A brief outline of the thesis:

1. Discuss the different modes of potential operation.
2. The different associated subsystems will be presented.
3. The immediate and most useful tasks capable will be outlined.
4. A program for testing and evaluating the performance of the task will be presented.

Chapter 2

Underwater Stud Welding; Modes of Operation

2.1 Introduction

Unlike prepackaged systems, which are most advantageous when used by submersibles, and conventional SMAW, which presently can not be performed by remote submersibles, the M.I.T. stud welding gun enjoys potential useage by divers as well as by telemanipulative capable submersibles. This chapter will discuss the different modes of utilization as well as their required configurations.

2.2 Diver/Salvor Operation

The first and potentially the most widespread mode of operation would be hand operated by the diver and the salvor. (Figure 2.1) Presently there are many tasks in whicn the diver and the salvor could utilize the underwater stud welding gun. These

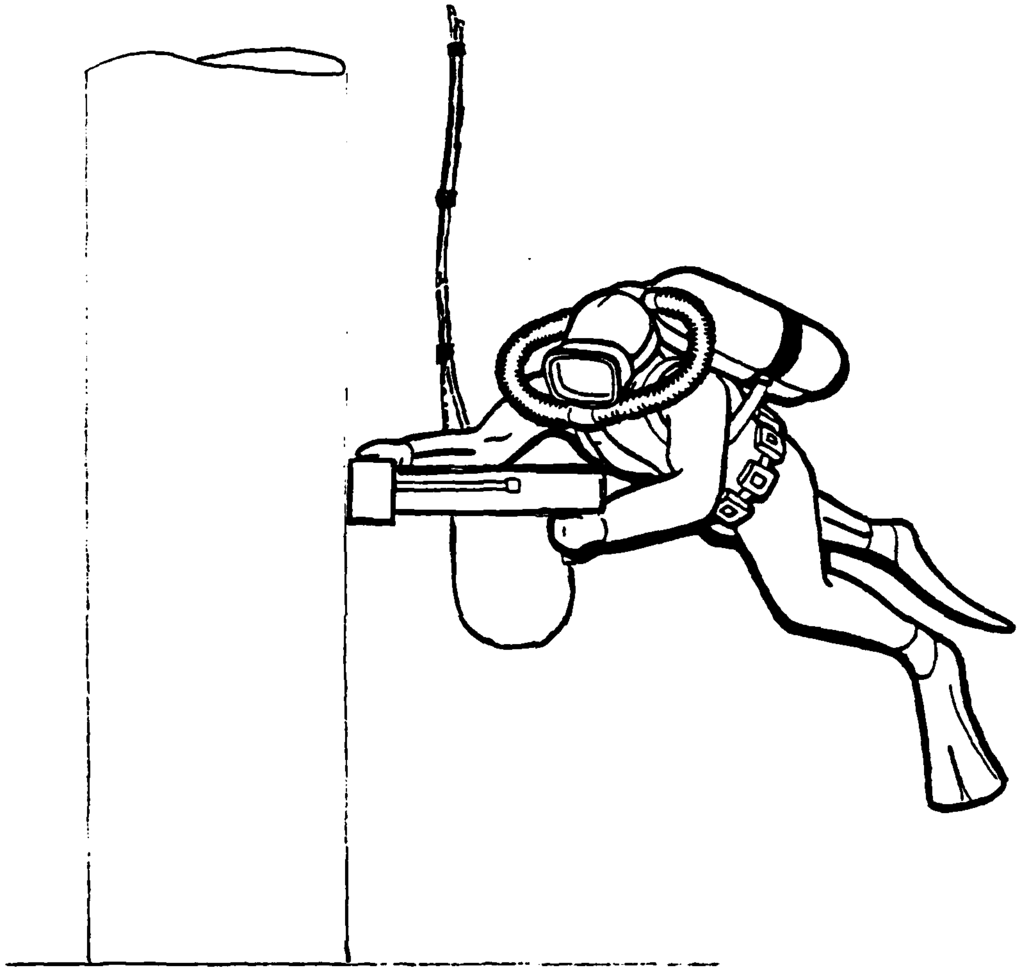


Figure 2.1 HAND HELD OPERATION

tasks, located underwater, in the splash zone, and on decks covered with water due to action of the sea, dewatering pumps, or flooding will be discussed in chapter 4.

2.3 Telemanipulative Operation

Like prepackaged welding systems the stud welding process is independent of the operator, other than for its geographical location and the time at which its process commences. Thus, an underwater stud welding gun is ideal for operation by manipulator equipped submersibles.

Telemanipulation is performing manipulation remotely. Supervisory control is where a human operator and a computer jointly control a remote system [9]. In a manually controlled system, the human operator is responsible for both command decisions as well as physical inputs to which a manipulator or system directly responds. In an autonomous system, the human operator is not able to exercize any control over the actions of the system [9]. An example of such a system is an untethered submersible preprogramed to travel to the ocean floor at a predesignated position, take a photograph or bottom sample, and return to the surface. The human operator is unable to alter the submersible's actions during any portion of the preprogrammed mission.

Supervisory control lies somewhere between the autonomous and manually controlled systems [9]. If the autonomous system described above were to have supervisory control, the human operator would be able to make command decisions on matters such as the location of the vehicle, the quality with which the core sample was taken and whether or not any intervention is required. If the system has failed to perform any of its preassigned tasks to the satisfaction of the operator, he is able to instruct the system to repeat an accomplished task and/or give the necessary instructions to ensure the task is performed properly. During the performance/reperformance of any task, the operator is free to monitor the system, thereby relieving him of the mental and physical fatigue of performing repetitive or precision sensitive tasks.

Though a manually controlled system could utilize the underwater stud welding gun, an underwater vehicle having a supervisory controlled telemanipulator is ideal. Supervisory control is ideal in its ability to rapidly and accurately perform repetitive tasks inherent to stud welding such as surface preparation, changing studs and turning nuts. In the the following chapters different tasks will be discussed for various manipulaton systems. Possible configurations of telemanipulator equipped submersible use of the stud welding gun are provided in Figure 2.2.

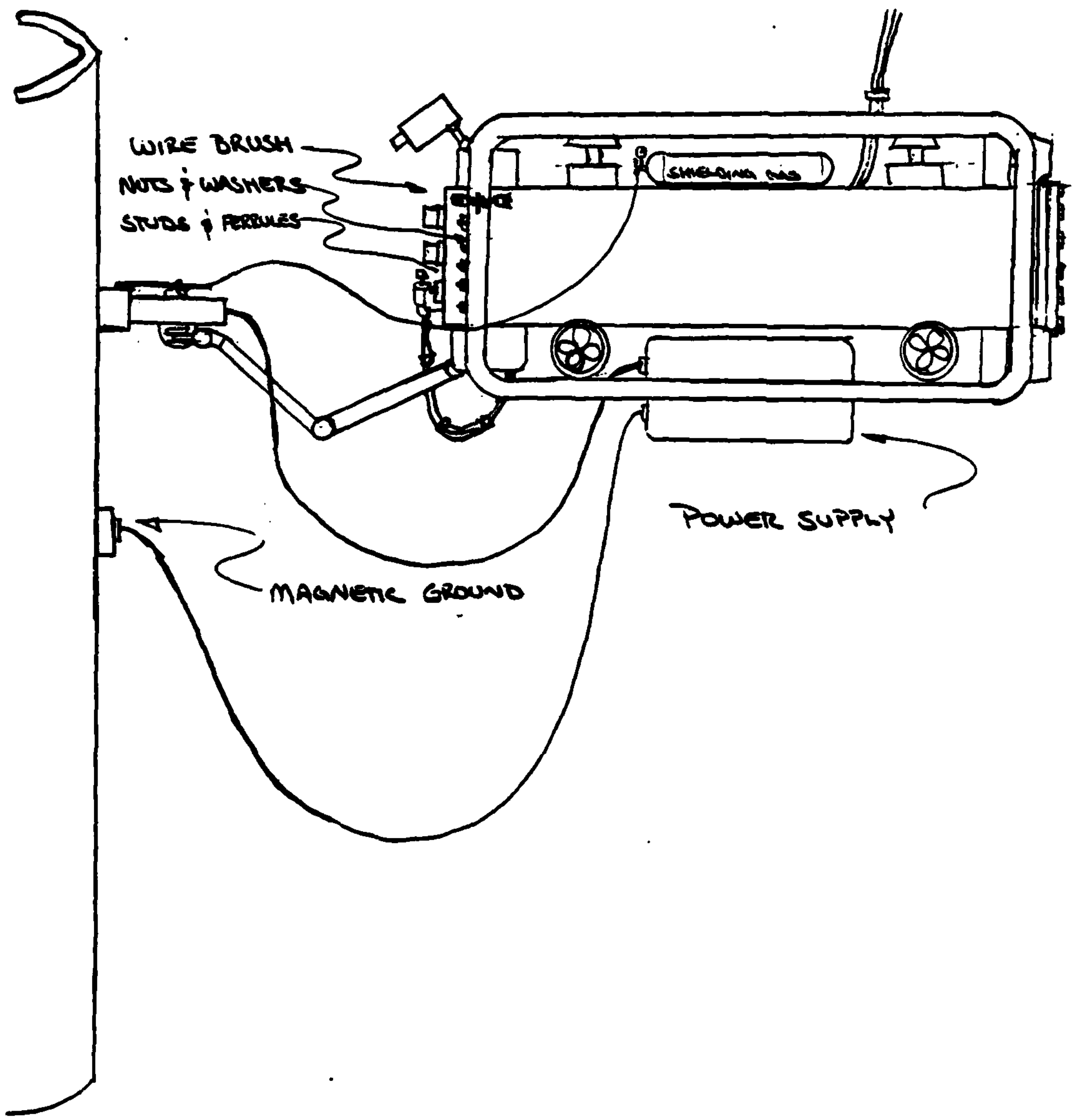


Figure 2.2 MANIPULATOR CONFIGURATION

2.4 Packaged Operation

The properties of the stud welding process and the configuration of the associated gun, enable the gun to easily be integrated into a stud welding package. Such a package has been suggested by von Alt [8]. Use of a package would be advantageous in that it can be utilized by underwater vehicles not having manipulators. Even vehicles configuring with manipulators can use this package to free the mechanical arm for the performance of other tasks. A stud welding package, like the stud welding gun, can be utilized by underwater vehicles regardless of the method of control, be it manual or supervisory. If utilized with a system having supervisory control, all the functions necessary to accomplish the subtasks, such as reloading, can be performed under the control of the computer. The package system has one degree of freedom, an undersea vehicle has at least four, thereby yielding at least 5 degrees of freedom for placement of studs. Useage will be a little more difficult than that by a manipulator with 5 or 6 degrees of freedom, as the entire submersible will have to be moved in order to properly align the stud gun. Possible configurations are displayed in Figure 2.3. Utilization of a package system will be discussed in the following chapters.

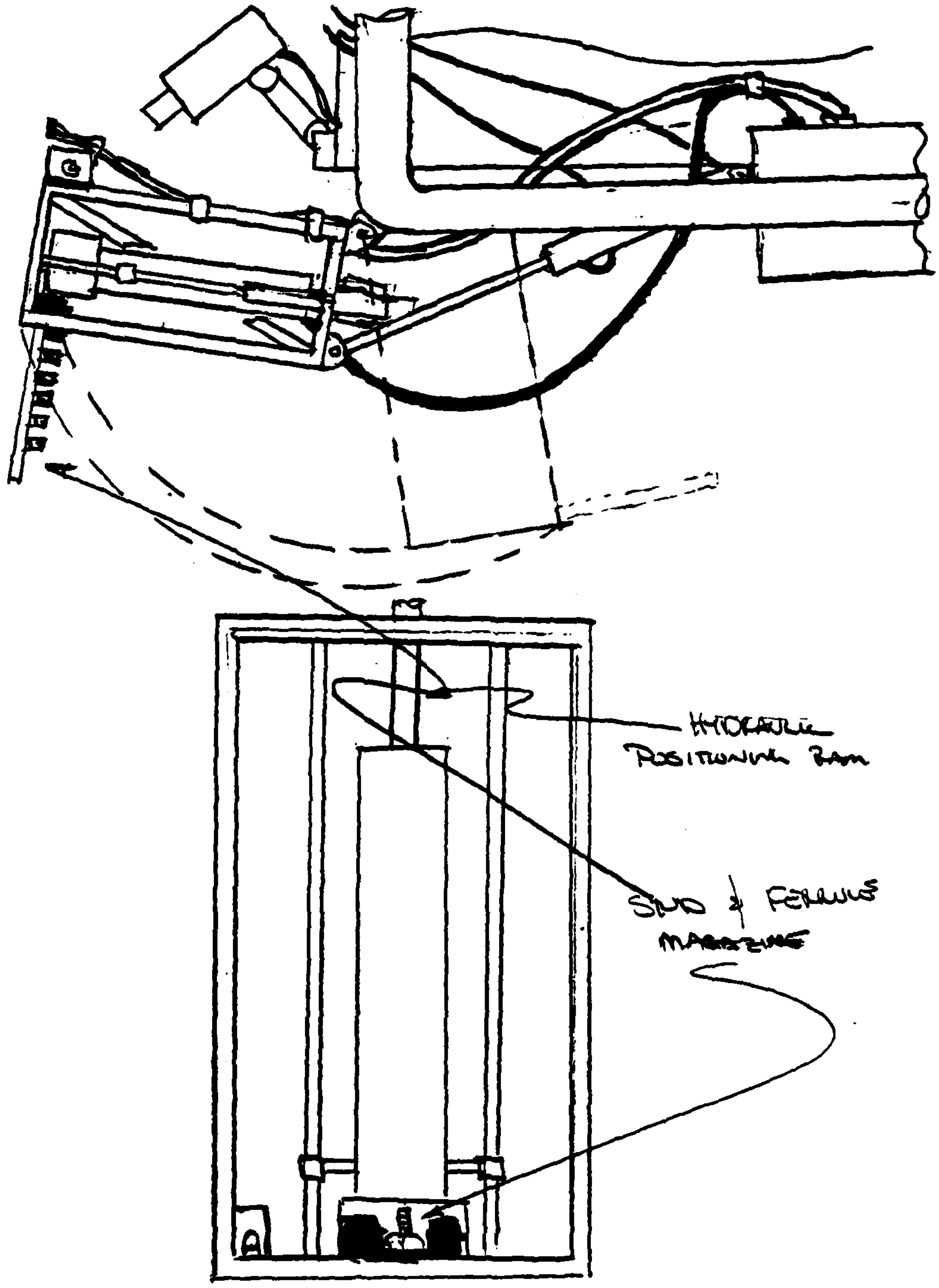


Figure 2.3 PRE-PACKAGED CONFIGURATION

Chapter 3

Power Supply, Shielding Gas & Associated Hardware

3.1 Introduction

The underwater stud welding gun, like other welding systems, is able to produce impressive results in the controlled environment of a laboratory. This chapter will discuss the obstacles encountered in an industrial marine environment, as well as the preliminary design of associated apparatus required to provide desirable results.

3.2 Power Supply

In stud welding the crucial parameters are voltage, current and weld time. The potential between the stud and base plate should be 40 volts which may require a larger circuit voltage depending upon the welding currency and the resistance of the cables. The current required is a function of the stud diameter. The required currents are given in figure 3.1.

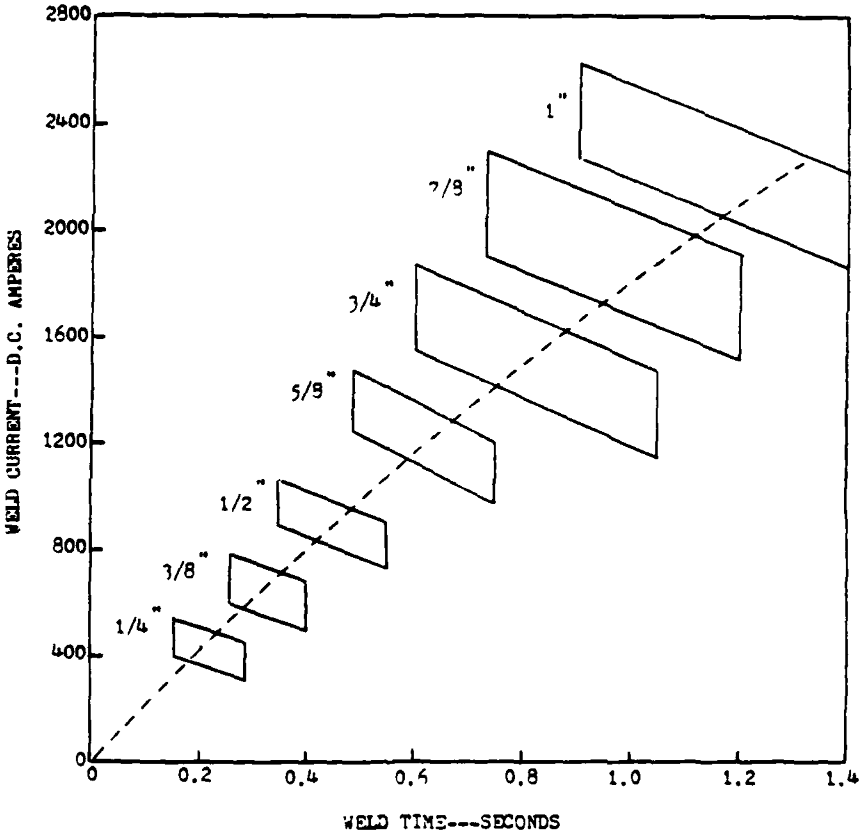


Figure 3.1 WELD CURRENT AND WELD TIME AS A FUNCTION OF STUD DIAMETER [2]

As the M.I.T. underwater stud welding gun has successfully welded 3/4" studs underwater, 1200 amps will be the upper limit in power consideration.

There are 3 ways by which welding power can be supplied to the stud welding gun:

1. Welding Machine
   a. Diesel or Motor/Generator type
   b. Transformer/Rectifier type
2. Capacitive Discharge
3. Batteries

The welding source can either be on the surface or at depth if enclosed in a dry box.

3.2.1 Stud Welding Machines

Due to the extremely low duty cycle, less than 2%, 1200 amp stud welding power can be supplied by a 650 amp welding machine configured with a stud welding control unit [10]. This control unit can either be located with the machine or at depth in a bry box. As the control unit is physically small it would be more advantageous to have the control unit at depth, accessable for diver input, than to run the control cable and control ground to the surface. Though the control cables are very small and do not tax the system with weight, they do stand the risk of failure when being fed over the side with the divers umbilical, welding power cable and grounding cable, if used. Diving operations, being complex enough, require the simplest and least labor intensive solutions. In this case it would be best to have the control unit at the weld site.

For stud welds in the deep, requiring a large amount of power, either the voltage drop or the diameter of cables required would make the weld impossible. In such situations the power source could be placed either in a dry box or in an oil filled box and submerged to the weld site. The welding power could then be transmitted to the transformer/rectifier (welding machine) at a high voltage, thus requiring a lower amperage and cables of smaller diameter. A 1200 amp weld at a depth of 600 feet to a base plate that requires grounding by the operator (active grounding) would require in excess of 5750 lbs of 750 MCM cable. If the transformer/rectifier is placed in a dry box, approximately 14 cubit feet for a 563 lb, 650 amp welding machine, its dry weight would be about 900 lbs. If concerned about leakage, the dry box would be oil filled, which would aid cooling providing about a 1500 lb. package. The power could then be transmitted down at 400 volts on a 250 MCM cable weighing less than 1000 lbs. This would reduce the in-water displacement by more than 40%. The smaller cable will not only reduce drag but also be more flexible allowing greater freedom of movement by the user, be it a saturation diver or an underwater vehicle.

Though the transformer/rectifier can be submerged in order to improve the system's performance this is not the best solution. Better solutions will be discussed in the follwoing paragraphs.

3.2.2 Capacitative Discharge

Capacitative discharge is a technique used in automated and other applications where a high rate of welding is required. There are some automatic stud feed systems that can weld 42 studs per minute [5]. Capacitive discharge uses a single complete compact transformer/rectifier/power-storage/control unit. Portable units are able to operate on 115 v, 60 Hz power, and weld 1/4" studs at a rate of eight to ten per minute [5]. As capacitive discharge systems have not been able to produce welds on studs greater than 1/4" without the application of special techniques, it will not be considered.

3.2.3 Battery Power

The use of battery power for the welding of studs underwater presents a promising future. Battery systems are inexpensive, durable and versatile in comparison with welding machines. Though welding machines have an unlimited endurance, and batteries are limited by the total amp-hours available, this poses little problem. Given, diesel starting batteries conform to the Battery Council International criteria of being able to deliver their rated amperage for 30 seconds (crank performance) and maintain 1.2 volts per cell at 0°C, industrial batteries will have little difficulty in delivering the required amp-hours. One of the largest jobs, power wise, considered for this underwater stud welding gun is the attachment of a 7 x 10 foot steel patch. Such a patch may require one 3/4" stud every linear foot of its parameter, thus requiring 34 one second welds of 1200 amps. As a 1200 amp diesel battery is capable of delivering 1200 amps for 30 continuous seconds it is conservatively estimated that such a battery system could deliver adequate power for 60, 1200 amp, one second welds of a duty cycle of 2% or less [11]. One is aware of a "near dead" battery's ability to deliver 3 or 4 more starting attempts after it is first apparently exhausted, when starting an automobile.

Based upon the temperature and the system voltage 4 to 7 batteries in series would be required to produce the desired current/voltage. If the welds are to be done within a few feet of the battery power system, as in a battery power system mounted on a submersible, voltage drop in the cables may be neglected. If the power needs to be transmitted more than a few feet, as in the battery power system being mounted in the submersibles "cage" or mounted on deck of a support vessel, there should be an allowance for a voltage drop of 10 v for use on deck or in a dry box, if properly heated or insulated, the number of batteries required can be reduced. (Ten volts was selected as the maximum acceptable voltage drop based on the voltage drop of recommended cables for specific operating amperages and cable lengths by Miller [10].) Figure 3.2 shows the number of batteries required as a function of temperature and voltage drop.

As the specific gravity of industrial lead-acid batteries is approximately 2, there is little difficulty in placing the batteries, control unit and insulation in a dry box resulting in neutral or slightly negative buoyancy, without the addition of ballast. The sizes and weights of battery dry boxes will be discussed in the following sub-section. Figure 3.3 shows the potential assembly of a battery dry box.

VOLTAGE DROP IN CABLES

TEMPERATURE		0v	10v
	0° c	6	7
	25° c	4	5

Figure 3.2 NUMBER OF BATTERIES REQUIRED AS A FUNCTION OF TEMPERATURE & VOLTAGE DROP

1.2v/cell @ 0° c, 1.7v/cell @ 25° c

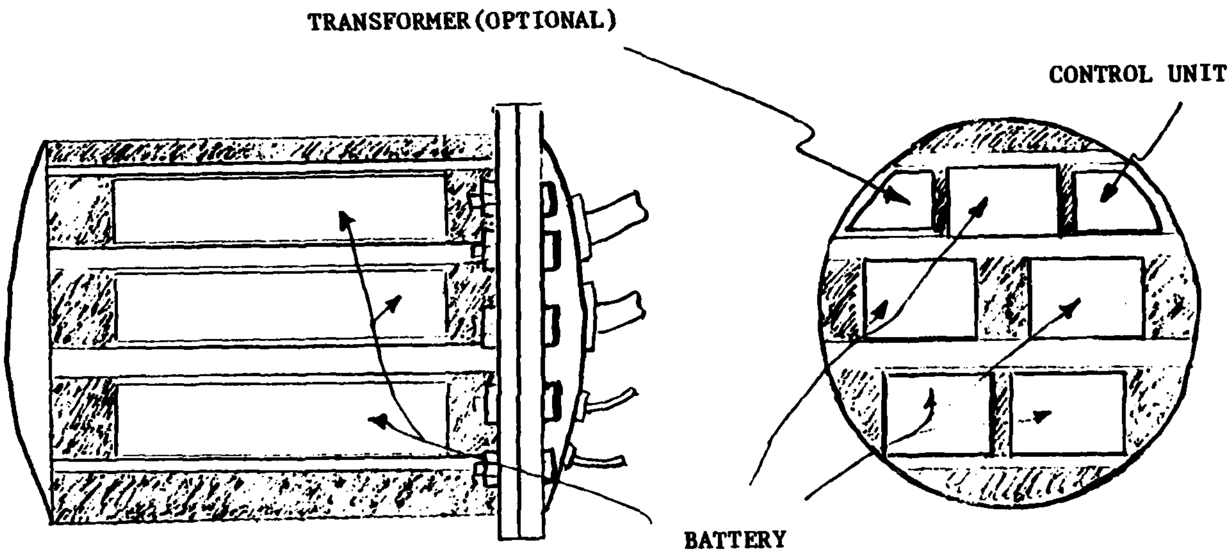


Figure 3.3 DRY BOX ASSEMBLY

Batteries have many advantages over the use of conventional welding machines.

1. Batteries are nearly equal in weight to a welding machine of equal capacity but are more portable.
2. Batteries do not depend upon ship power.
3. Use of batteries can reduce the amount of cable required.
4. Batteries are less expensive than welding machines.
5. Batteries are more easily obtained than a welding machines.
6. The batteries can be used for other purposes when not being used for welding.

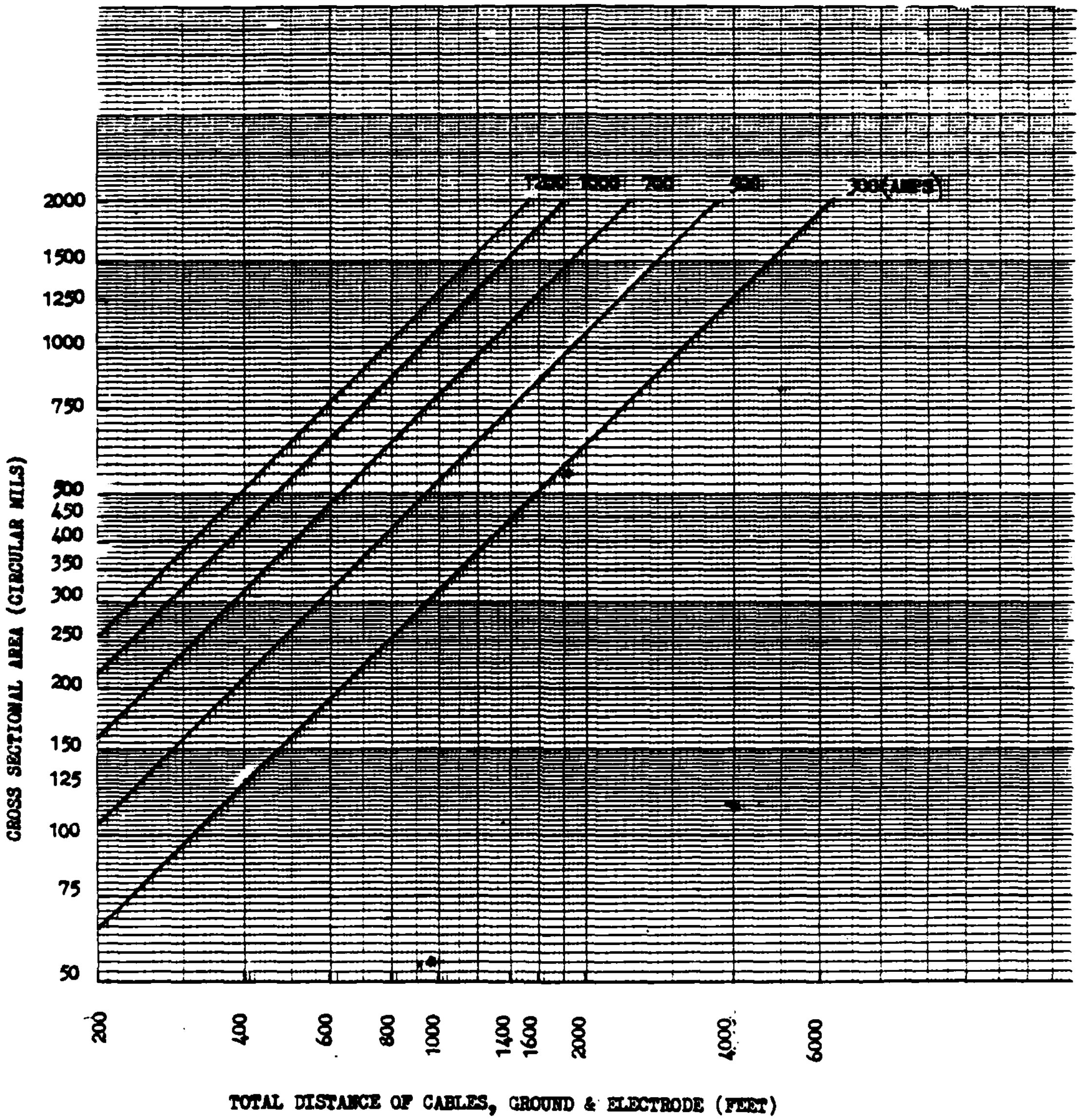
If the user is concerned about the amp-hours available from a particular battery power system, there is no difficulty in configuring a dry box, submersible, or battery bank with a charging system. Such a system would not weigh more than 100 lbs for a bank of 7, 1200 amp batteries and would be required to provide not more than a 20 amp trickle charge, in order to keep a battery bank fully charged before each underwater stud weld [11]. The size of the cables required to deliver the charging current would be negligible.

3.2.4 Welding Cables and Gas Supply

In welding at any significant distance from the power supply, power transmission becomes the primary concern. As welding cables are typically pieced together from sections of 50 feet, great attention must be given to the connections of these sections. If sound and waterproofed connections are not made, a great deal of power will be lost. As the use of batteries can greatly reduce the length and diameter of cables required, hence reduce the number of connections, they have been suggested as the optimal power supply system.

In order to ensure freedom of movement of the diver or manipulator, a short whip of 15 feet of 2/0 or 1/0 cable should be attached to the end of the transmission cable regardless of the amperage required. Such a configuration is standard practice and has been suggested by Schloerb [2].

When structures to be welded are passively grounded, such as offshore platforms, and ships having the welding power supply aboard the size and weight of the welding cables required are greatly reduced. Figure 3.4 gives the cross sectional area required in circular mils as a function of the total distance of cables used and the amperage. This figure was constructed using 10v as the permissable voltage drop. Figure 3.5 gives



1200
1000
700
500
300 (AMPS)
2000
1500
1250
1000
750
500
450
400
350
300
250
200
150
125
100
75
50
CROSS SECTIONAL AREA (CIRCULAR MILS)
200
400
600
800
1000
1400
1600
2000
4000
6000
TOTAL DISTANCE OF CABLES, GROUND & ELECTRODE (FEET)

Figure 3.4

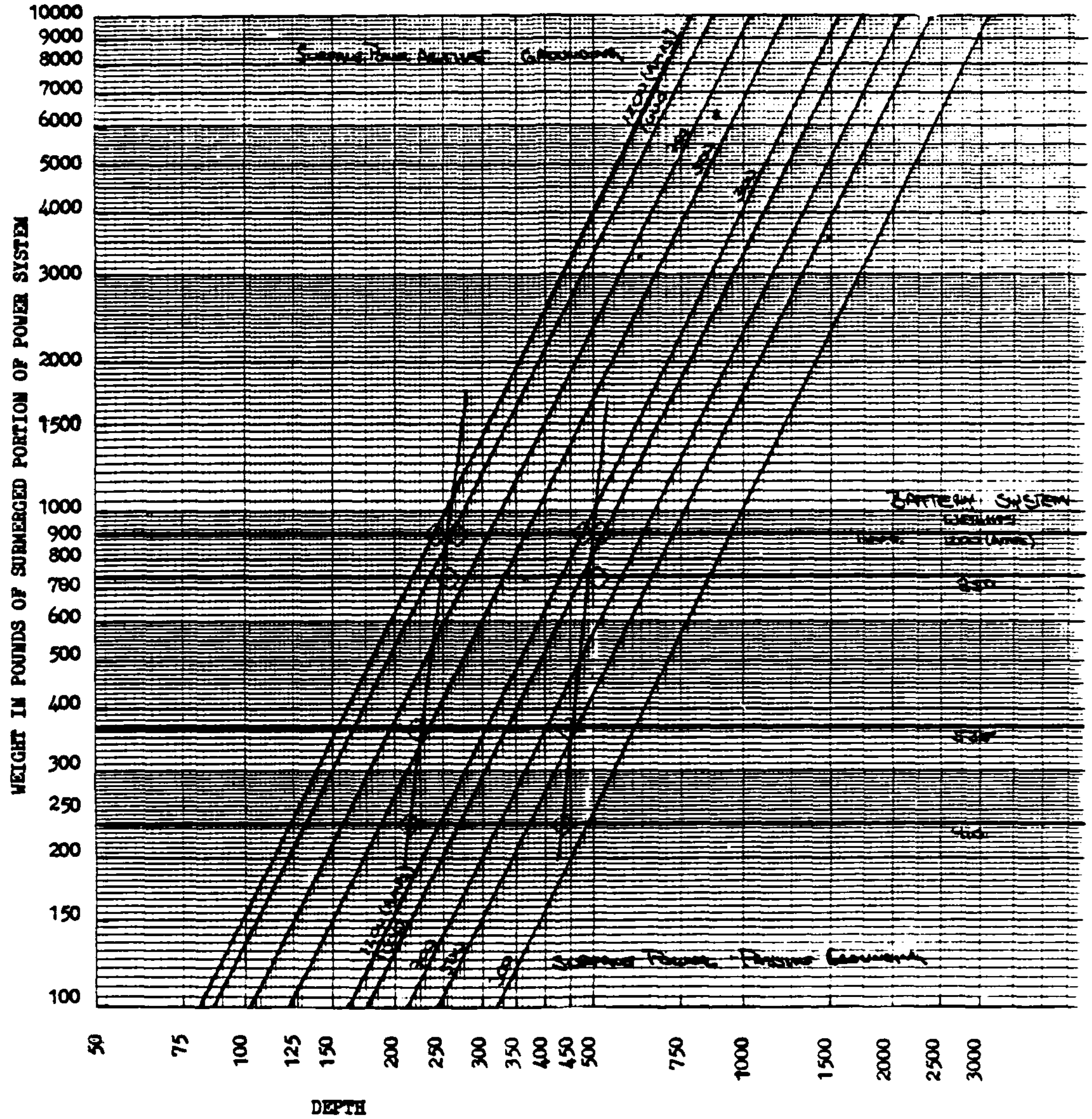


Figure 3.5 DEPTH vs. WEIGTH

the weights of submerged battery power systems and the weights of welding cables used. For the battery systems, (5 batteries) weight is a function of amperage, whereas for a surface supplied power system, weight is a function of amperage, depth, and whether or not the structure is passively grounded. Figure 3.6 shows a structure which is passively grounded, and a structure which is actively grounded. Welding to passively grounded structure at the same depth and amperage as welding to an actively grounded structure will require one fourth the weight of cable. Upon reviewing figure 3.5, it can be seen by using weight as the selection criterion that submerged battery power supply systems become the optimal power solution for stud welds on actively grounded structures deeper than 200 feet and for welds on passively grounded structures deeper than 400 feet. These lines are provided in figure 3.5 where it can be seen that the battery solution emerges as a function of depth, virtually independent of the amperage required.

Given the actively grounded surface powered vs submerged battery trade off depth of 200 feet, where the weight of the battery system becomes less, drag forces should be investigated. Upon investigation at expected maneuvering speeds of 1 to 4 feet per second, one finds the coefficient of drag for the cables required to be an order of magnitude higher than that of the required 14 cubic foot battery dry box. In

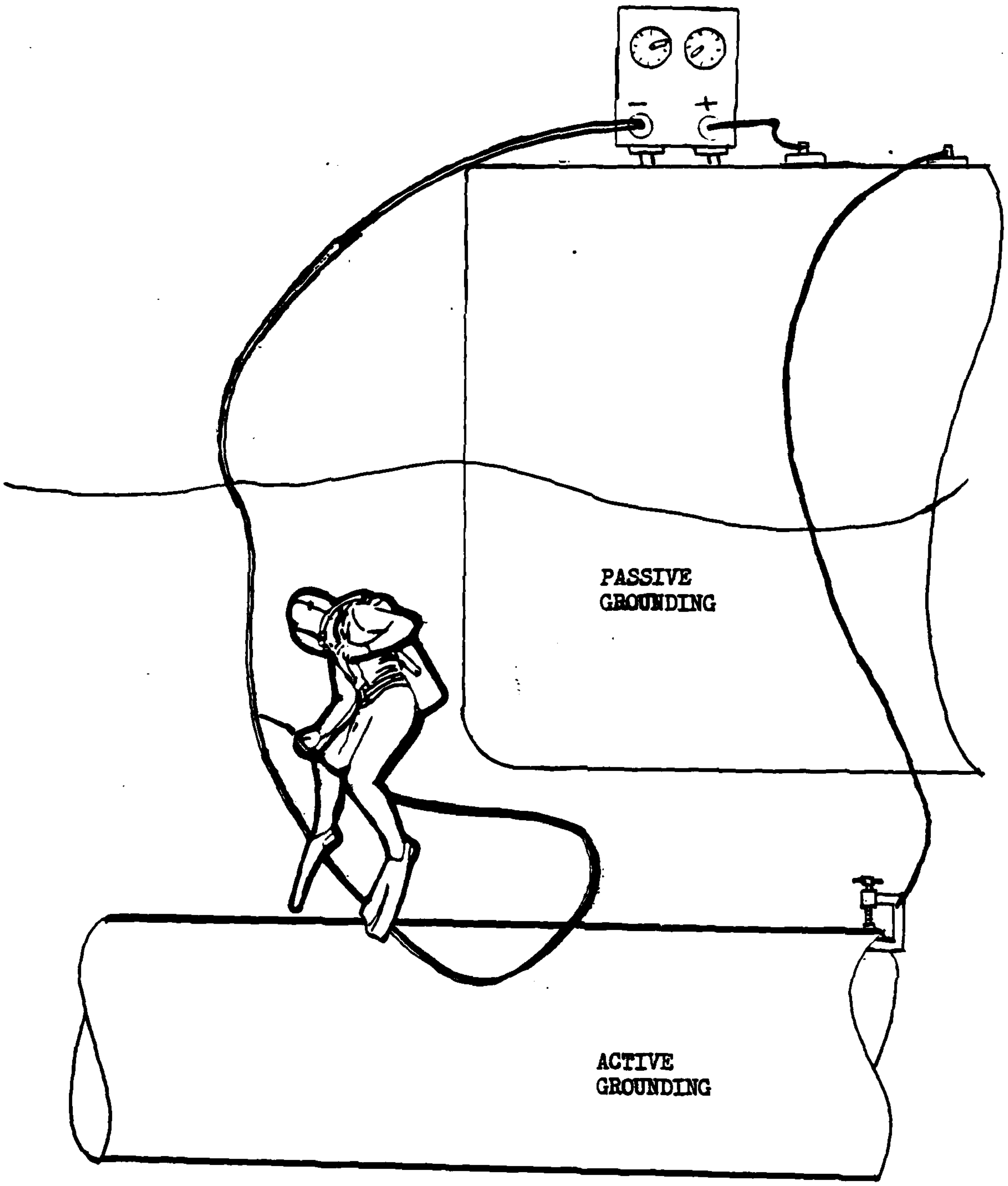


Figure 3.6 ACTIVE & PASSIVE GROUNDING

addition the surface area of the battery box is only a fraction of that of the cable. When considering drag, the depth at which batteries become the optimal solution is greatly reduced. Without synthetically producing weighing criteria, in order to produce an otherwise arbitrary trade off depth, the author recommends battery boxes with short, 15-30 foot, whips be used over surface supplied power on tasks requiring active grounding deeper than 100 feet and on task passively grounded (if welded by surface power) deeper than 200 feet. Other facters such as the lack of availability and cost of the required cables for a surface powered welding operation will also tend to drive the optimal solution toward batteries. Whenever a submersible is used, a battery power supply should be carried, the exception being for extremely small craft which would not be able to provide the necessary thrust to efficiently carry a battery system. It should be noted that underwater vessels of this size would also have great difficulty handling cables of any significant size, thereby greatly limiting their excursion radii as well.

Figure 3.7 is provided in order to determine the size of cables required for a given amperage, depth and excursion radius (see figure 3.8). For example, given a saturation diver or submersible to do the stud welding of 1/2" studs to an actively grounded structure at a depth of 600 feet. By entering with

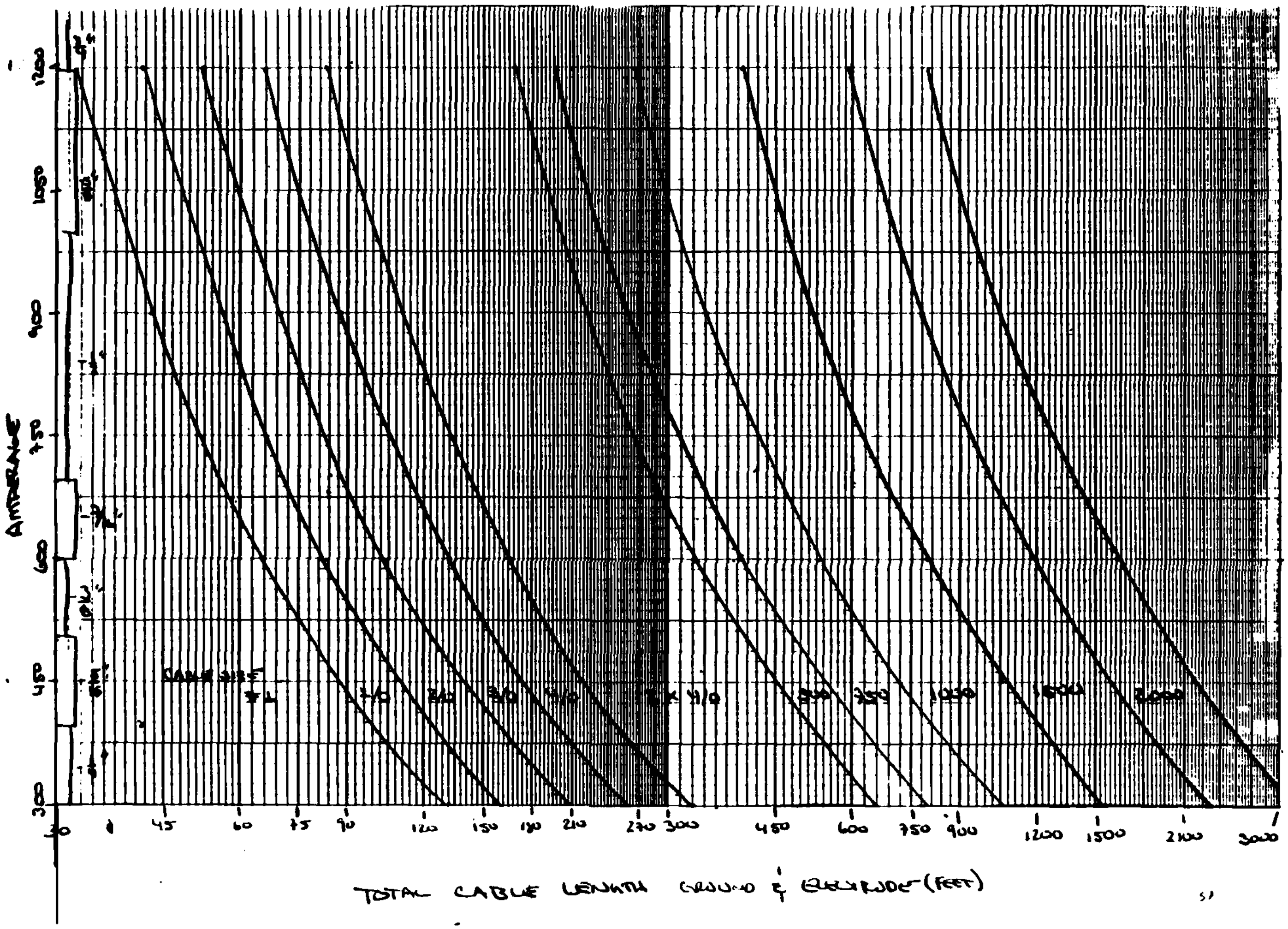


Figure 3.7 CABLE SIZES

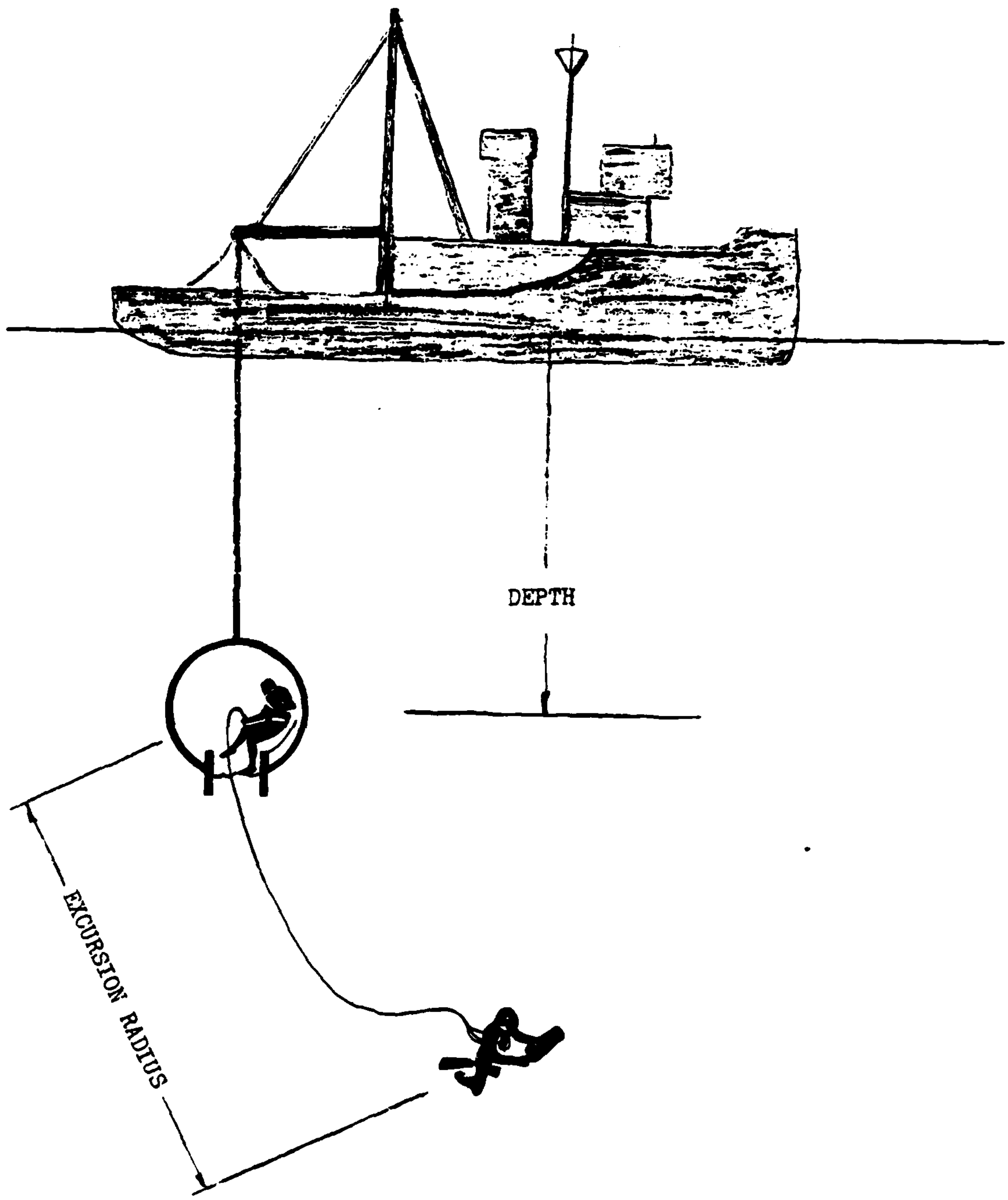


Figure 3.8 EXCURSION RADIUS

1200 feet (twice depth because actively grounded) and 700 amps it can be seen a 2000 MCM cable will be required. Yet this only solves half the problem. If the diver/submersible is required to have a 100 foot excursion radius, 200 feet at 700 amps must be entered to determine that two 4/0 cables in parallel would have to be used, for both the electrode and the ground. The last 10 or 15 feet of each excursion cable being 1/0 or 2/0 in order to allow freedom of movement.

Figure 3.7 can also be used to dertermine excursion cable sizes for battery power application. 10 volts being the voltage drop criteria as opposed to 5 for which the chart was drawn, and submerged battery power systems being advatageous by weight if actively grounded, the excursion distance need not be multipled by 2, even though actively grounded. For example, given a diver and a diving stage to the bottom of which a battery box is attached, what size cables would give him an excursion radius of 75 feet to make 3/4" stud welds?: a single 4/0 cable on both the ground and the stud welding gun.

For many of the same reasons the power supply is submerged, the shielding gas supply should be as well. Not only does the shielding gas supply hose add weight, and drag, thereby hampering the maneuverability of the system but in addition there is the head loss to be considered. For these reasons, in addition to the operator being able to regulate the gas flow whenever the power supply is submerged, the gas supply should be submerged as well. If a 3000 PSI, 700 cubic inch aluminum cylinder is chosen as the type flask to be used, Figure 3.9 gives the number of welds that can be shielded as a function of depth. This is for a mass flow rate that equals twice that of the volume of the chamber per second and gives 5 seconds of shielding per weld. This is to allow one second to displace the water in the chamber. One second for the weld and three seconds to reduce quenching.

A flask of the size mentioned is 26.5" in length and 7.7" in diameter. (A standard aluminum-90 SCUBA bottle) [12]. As the gas is used the flask's buoyancy will change from slightly negative to slightly positive. This change will have little effect upon divers. As most submersible capable tasks will require only a few studs, a much smaller flask's may be mounted on the craft, yielding a negligible effect due to buoyancy change.

3.3 Grounding/Attachment

Passively grounded workpieces obviously do not require grounding. In stud welding there are 3 basic ways to actively ground a work piece.

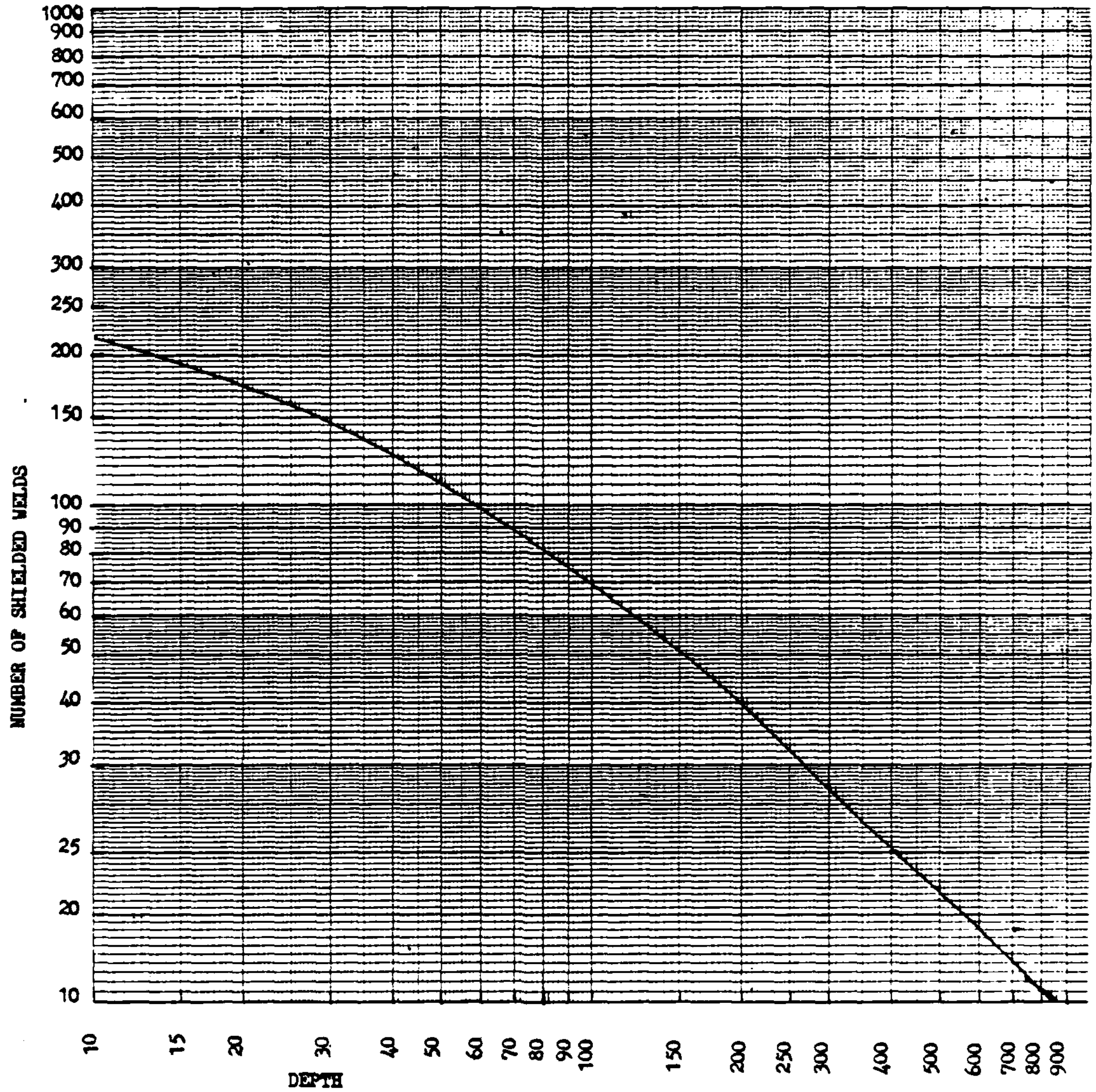


Figure 3.9 SHIELDING GAS ENDURANCE AS
A FUNCTION OF DEPTH

1. By the use of C-clamp or spring loaded ground
2. By an independent magnetic ground
3. By a magnetic ground mounted on the stud gun

The latter two methods are advantageous in that work pieces such as underwater pipelines and tubular members of an off shore platform, which fail to provide an appendage to which a spring or C-clamp type ground can be mounted, can be grounded easily. With the last method, the necessity for the separate step of grounding is eliminated. This is advantageous for telemanipulative systems.

The magnetic grounding/attachment system could either utilize electrical or permanent magnets. The author believes that permanent magnets which can be shorted, such as the type used in the mounting of machine shop instruments, should be used. This is because they can be turned on and off just as an electrical magnet, yet they do not require a power source. If hand operated, they will not require any servo switching system. If used by an undersea vehicle, the magnet system will require servo activated shorting switches.

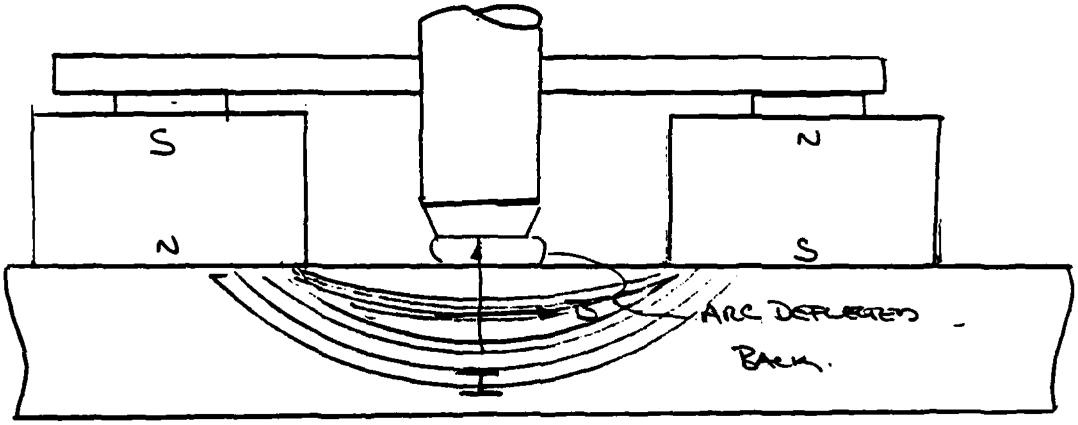
There are two major disadvantages of a magnetic grounding system.

1. It can only be used on magnetic materials.
2. The magnetic field of the grounding system may deflect the stud welding area. (if mounted to the stud gun). Figure 3.10

Tubular structures are the only type that would require a magnetic ground. Fortunately, these types of structures, underwater pipelines, and offshore platforms, are made of steel. As steel is the prevalent material used in the construction of ocean structures, there will be little difficulty in using a magnetic ground.

Aluminum objects requiring welding underwater would be found in the form of aircraft debris or small boats, both of which afford ample edges on which to attach a C-clamp or spring type clamp.

As the arc tends to deflect away from the area of the strongest magnetic field, the magnetic ground should have both the north and south poles in contact with the base plate. It should also be far enough away from the arc as to not have any significant



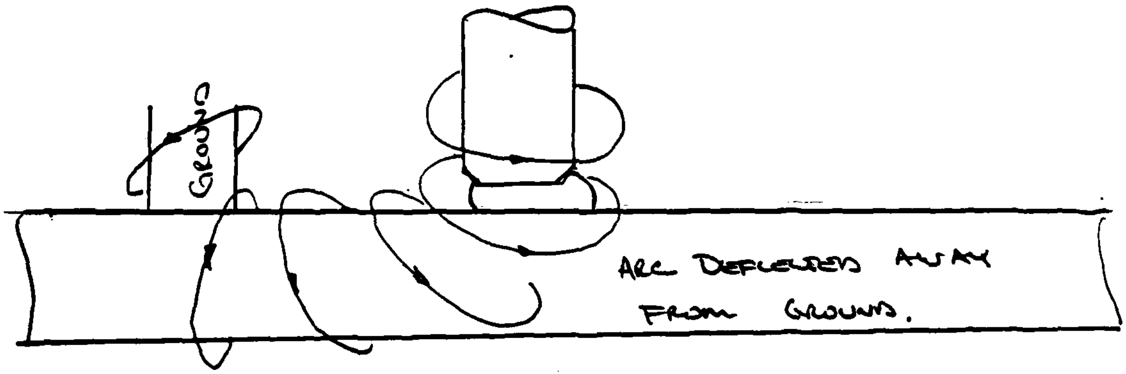


Figure 3.10 ARC DEFLECTION

effect and be mounted in such a way as not to interfere with the welding of subsequent studs. Figures 3.11 and 3.12 describe the type of ground used by Schloerb and the type recommended by the author.

3.4 Surface Preparation

When welding underwater, as on the surface, the base plate must be cleared to bare metal. Underwater, this is more difficult than on the surface. Work pieces are, in addition to rust, often covered with paint, and various types of marine growth (algae and barnacles being the most prevalent). Because of the density of the water and the diver's bouyancy, he losses a great deal of leverage and finds the cleaning of objects most difficult. When cutting with stick electrodes, the diver only cleans a small section in order to initiate an arc. When welding, the diver is required to clean the entire track to be welded. Surface preparation being difficult, divers do not always do a thorough job. As stud welding requires a much smaller surface area to be cleaned, the diver can do a better job. The best method of cleaning is to use a cavitation cleaning device. Such a device is easier to use than hydraulic or pneumatic tools, however, it is not universally available.

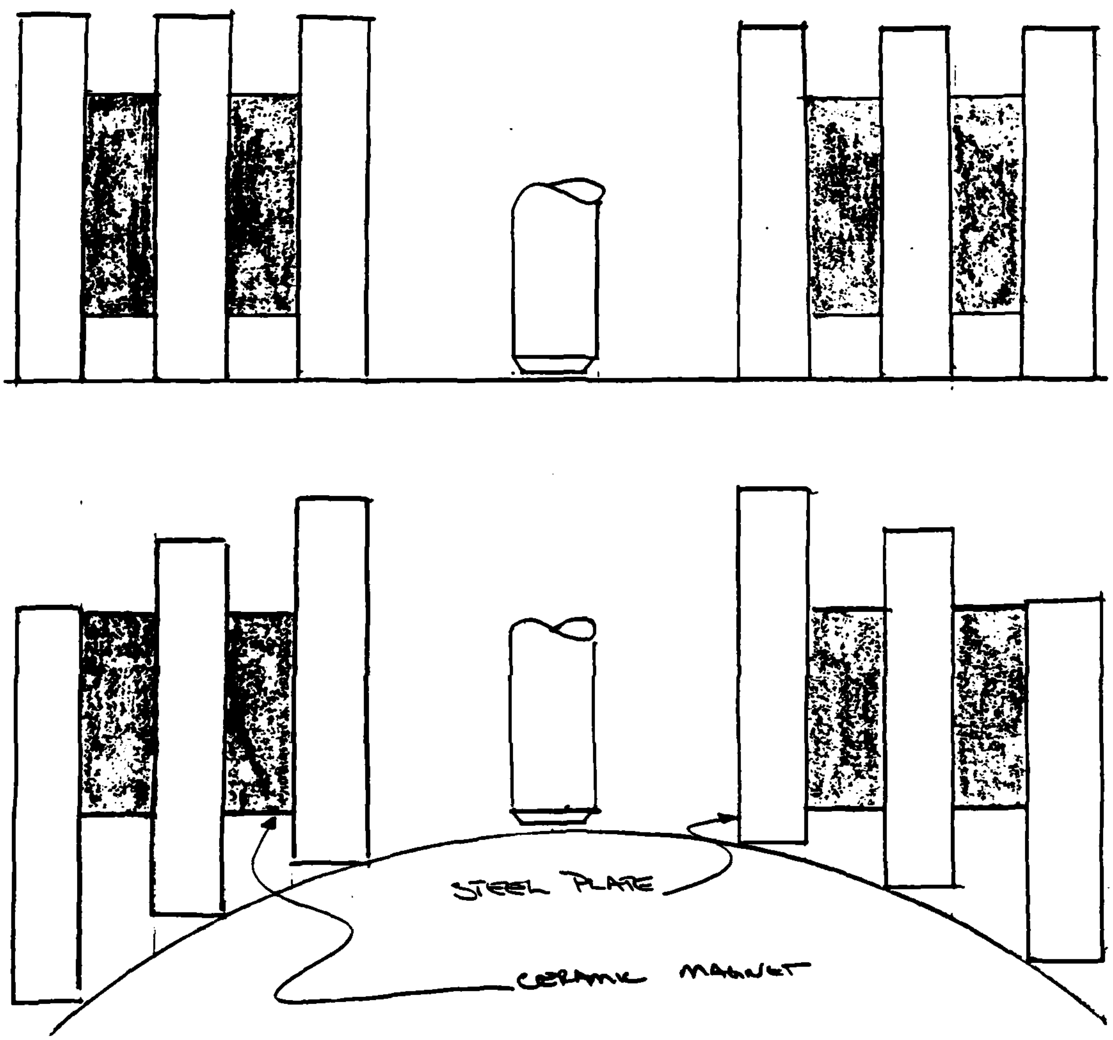


Figure 3.11 SCHLOERB GROUND [2]

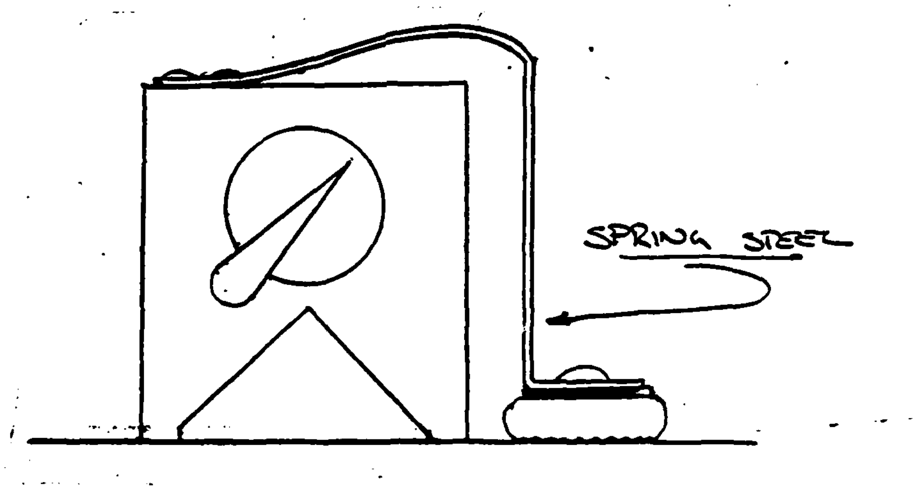


Figure 3.12 MAGNETIC GROUND

As most of the studs to be welded underwater will be threaded to perform their tasks, hydraulic or pneumatic wrenches will be required to drive the associated nuts. Such a device being required on location can easily turn a wire brush to accomplish the cleaning. For telemanipulative use, being at great depth where pneumatic pressure is greatly degraded, and having hydraulic drives in many vehicles, hydraulic tools should be used. Figure 3.13

3.5 Ferrules and Templates

Ferrules are used to perform several functions during welding: [3]

1. To concentrate the heat of the arc in the weld area.
2. To restrict the flow of air into the weld area, which helps to control oxidation of the molten weld metal.
3. To confine the molten metal to the weld area.
4. To prevent the charring of adjacent non-metal materials.

Ferrules, which are composed of a ceramic material, are cylindrical in shape. To allow the expulsion of gases created in the weld area, the bottom of the ferrule is serrated. It has an internal shape which forms the displaced molten pool

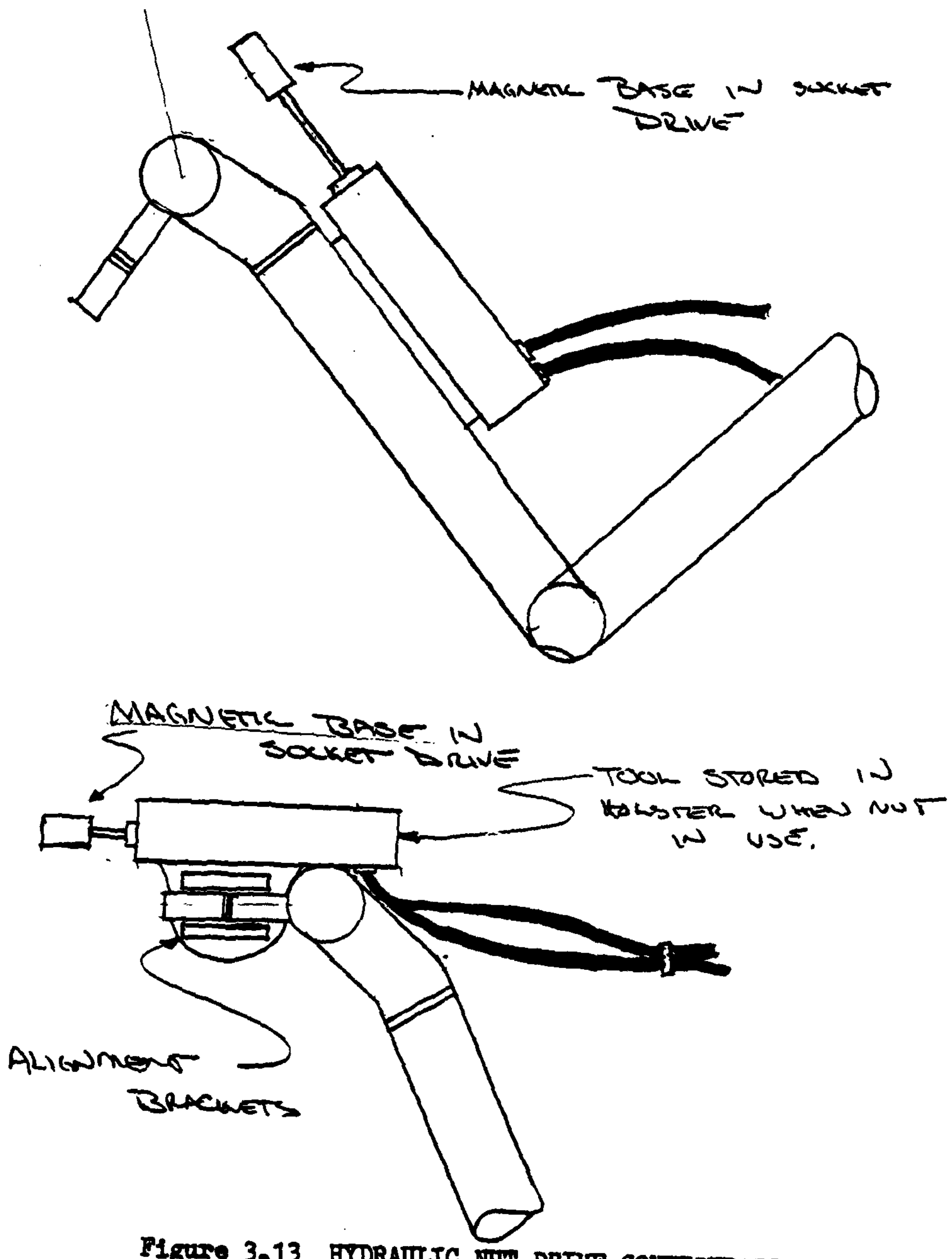


Figure 3.13 HYDRAULIC NUT DRIVE CONFIGURATION

into a fillet around the base of the stud. Ferrules are available in various special configurations which permit welding to substrates of low radii of curvature or to substrates at angles other than 90°. One of the only underwater stud welding tasks where special ferrules would be required, is for the attachment of a hot-tap flange, using large (3/4") studs, (stud-tap) to a pipe of 6" diameter or less. For this particular task, smaller studs could be used, thus eliminating the requirment of a special ferrule. However, there would still be a major problem in stud positioning and gas shielding. A special shielding foot, curved to match the pipe, could be used to relieve this problem, but the problem of stud positioning would still persist. Figure 3.14. The best solution of this problem would be to use a cold tap.

Of the above functions, restricting air flow is of little importance as the stud gun at present uses a shielding gas. The fourth function of preventing charring is important if special templates are used.

When using templates in stud welding for accurately locating studs, the ferrule is centered in the template. Because of ferrule manufacturing tolerances, the accuracy of stud location is 1/32" [3]. The template is elevated 3/32" in order to facilitate the venting of gasses through the serrated section of the ferrule. (See Figure 3.15)

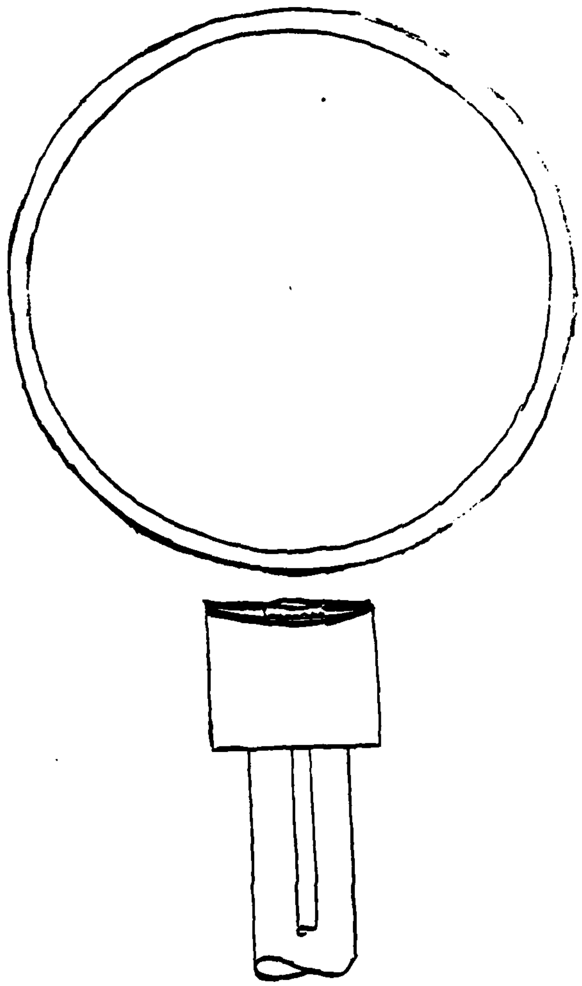


Figure 3.14 SPECIAL SHIELDING FOOT FOR STUD WELDING TO TABULAR STRUCTURES

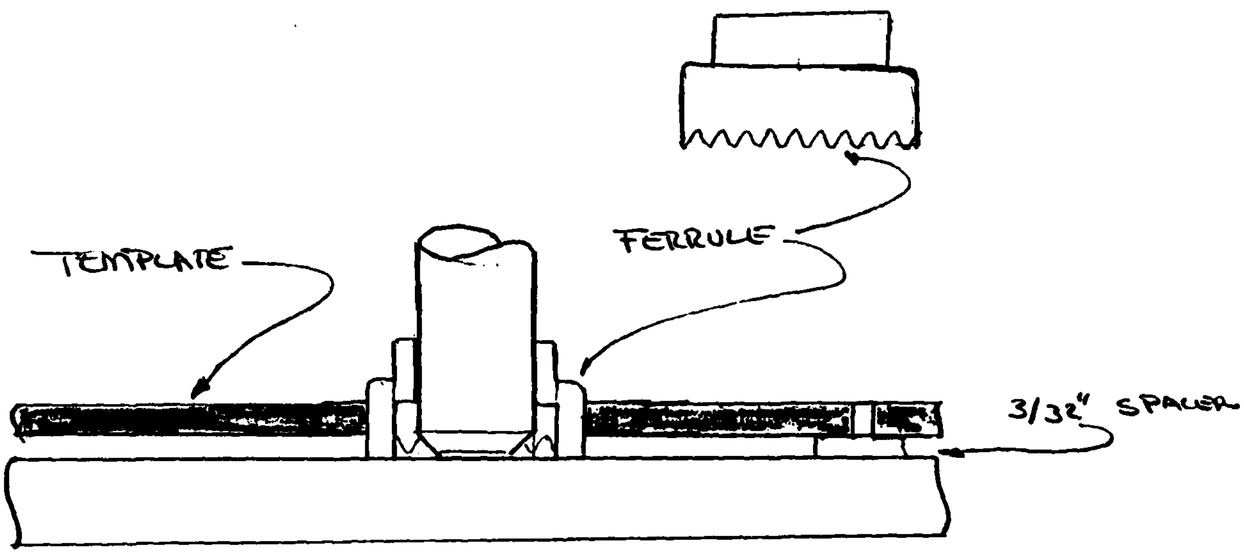


Figure 3.15 STANDARD SURFACE STUD WELDING TEMPLATE

This type of template is not acceptable for underwater stud welding, as the shielding gas would have great difficulty displacing the seawater under the template.

There are two types of stud locating templates that can be used. The first being the shielding foot template. Figure 3.16. This type is very advantageous in that it allows for adequate protection by the shielding gas and is not influenced by the ferrule tolerances. This type of template easily could be fabricated from a material such as 1/4" plywood. This template is so named as it is aligned with the shielding foot of the stud gun.

The second type is the gasket/template type (Figure 3.17). The gasket/template type configuration is so named because it not only acts as a template to align the studs but remains in place to act as a gasket providing a water/air tight seal. The gasket/template is serrated around its perimeter in order to allow the ventilation of welding and shielding gases and hold the ferrule firmly in place. With this type of template a tight adhesive should be used to bond both the stud and the template to the ferrule. This would allow all the studs, ferrules and the gasket to be positioned on the work piece as a single unit. The adhesive must be light enough to allow the retraction of the stud during welding to be strong enough to

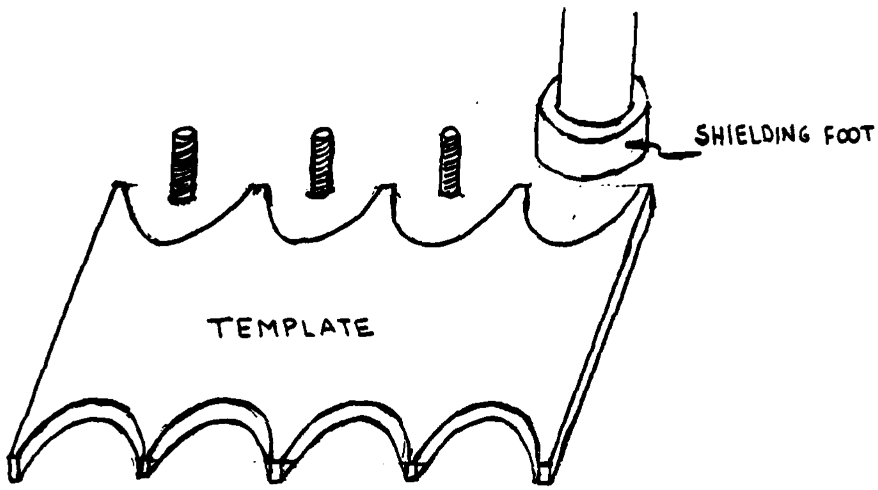


Figure 3.16 SHIELDING FOOT TEMPLATE

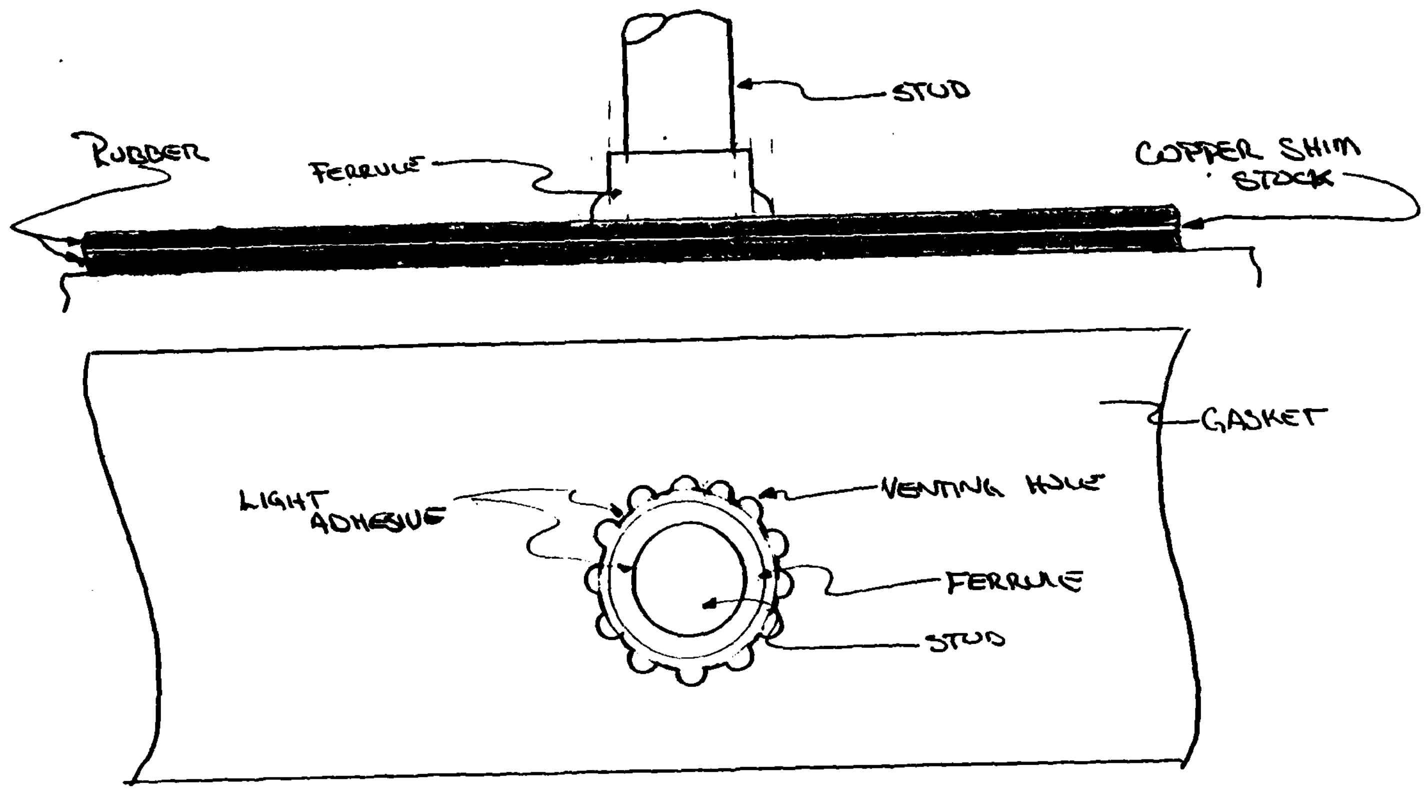


Figure 3.17 GASKET/TEMPLATE

keep the assembly in tack during positioning. A gasket/template should only be used for those types of tasks which require a gasket and do not vary in physical size (as they will have to be fabricated long before their intended use.) This type of template also requires modification of the shielding foot. As the M.I.T. underwater stud welding gun presently positions and withdraws the stud with respect to he bottom of the shielding foot, it should be modified to accomodate threaded or interchangeable feet. The shielding foot could then be either exchanged or withdrawn in order to accomodate the thickness of the gasket/template.

The gasket/template would have to be of 3 ply construction. A center ply of firm yet easily plastically deformable material, such as copper sheeting and two outer plys of rubber could be used to provide an air/water tight seal.

Chapter 4

Utility and Task Description

4.1 Introduction

The tasks which can be accomodated by the underwater stud welding gun vary widely. In this chapter the tasks are divided categorically into the areas of application. The tasks, hardware, associated equipment and expected performance will be discussed.

In addition to 3/4" studs being the largest size demonstrated, there are other reasons for selecting this size for study. 3/4" studs require an amperage which is at the limit of commercially available lead-acid batteries without placing the batteries in series, requiring 8-14 batteries to accomplish a particular task. One may ask, can tasks be accomplished simply by using more studs of a smaller size? The answer is obviously yes. But, by using less studs of a larger size, there will be the following advantages:

1. there are less components
2. there is less time spent welding and mounting the fixture
3. there is less time spent in surface preparation
4. those tasks limited by the number of studs have a greater strength.
5. the less studs used, the less accuracy is required in the positioning of the studs in order to effect a joint (greatly increasing chance of proper fitup)
6. larger studs, washers and nuts are easier to work with for both divers and manipulators.

The last two points cannot be emphasized strongly enough. As diving tasks should be as simple as possible, the old salvage rule of bigger is better strictly applies. A diver given more components of a smaller size will have greater difficulty in using the components and a much more difficult time in recovering them if they are lost. Tasks requiring more studs will require much more time top side as well as underwater. There is also the increased chance the component to be bolted to the studs will not fit, with an increase in the number of studs. If ships should elect to use installed welding machines (which are typically 400 amps) vs. batteries or larger machines, they will be limited to studs of a 7/16" or 1/2" in diameter. This will result in structures having 34% of the strength of those fabricated with an equal number of 3/4" studs or structures of equal strengths requiring 3 times the number of studs and 3 times the fabrication period.

4.2 Salvage and Repair

The M.I.T. underwater stud welding gun should find great utility in the field of salvage and repair. As conditions may drastically change from day to day, and long range planning is nearly impossible, salvage operations efforts are ususally done in series and are difficult to manage. It is not unusual for an entire salvage operation to come to a complete halt for several hours awaiting the completion of a welding task. As typical marine salvage operations cost from $8,000 to $80,000 per day, the accomplishment of a single task being completed 10 minutes sooner could represent a savings of more than $1,100.

In this section the potential useage of underwater stud welding will be demonstrated in the area of salvage, repair and damage control. In salvage operations, tasks are performed on the surface, in the splash zone and to depths beyond those attainable by divers. Salvage not only encompases the raising and refloating of sunken or stranded vessels but the search for and recovery of sensitive objects as well. Given in Figure 4.1 are the characteristics and properties of various sizes of studs.

4.3 Padeyes

Salvage operations often call for the use of padeyes, for both the lifting of objects as well as the mounting of turning blocks. Padeyes come in many forms and serve many purposes.

4.3.1 Single Stud Lifting Padeye

There is a need for an underwater stud welding assembly that does not require any mechanical tasks of the operator other than stud welding in the attachment of a lifting padeye. This would be used by divers at depths where other methods of attaching lifting lines would require bottom times approaching those of exceptional exposures (bottom times at great depths which jeopardize the safety of the diver). A single stud welded padeye would also find utility by submersibles which either are configured without manipulators and/or are employed in a bottom search. Upon locating a lost object, the lifting

CHARACTERISTICS

DIAMETER AND THREAD D	MIN (AW) LENGTH A	H	MIN (AW) LENGTH L	WELD BEAD DIMENSIONS E	F	STUD X-SECTION AREA	ULTIMATE TENSILE LOAD TONS*	ULTIMATE SHEAR LOAD TONS
1/4-20	1/4	.217	5/8	5/16	3/32	.037	1.36	1
5/16-18	1/4	.275	5/8	13/32	7/64	.059	2.19	1.6
3/8-16	1/4	.312	5/8	7/16	7/64	.076	2.82	2.06
7/16-14	1/4	.375	3/4	1/2	1/8	.110	4.07	2.98
1/2-13	5/16	.437	3/4	19/32	9/64	.150	5.53	4.05
5/8-11	5/16	.500	7/8	11/16	5/32	.196	7.24	5.30
3/4-10	1/2	.625	1-1/8	7/8	3/16	.306	11.31	8.29

* Based on results of Kataoka.

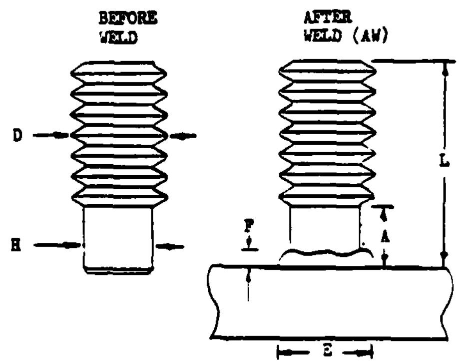


FIGURE 4.1 STUD DIMENTIONS & STRENGTHS [10]

stud could be welded to the object in order to either mark it with a buoy or lift it to the surface. The preliminary design of the apparatus required is shown in Figure 4.2.

This lifting stud assembly is held in a sacrificial cannister. A special chuck to hold the ring of the padeye would also have to be inserted into the gun's standard stud chuck. A 1" shackle is fed through holes around which the sacrificial cannister is built and made water tight with silicone sealent. As the stud is raised only 3/32" during welding, the shackle will not interfere. After welding, the gun is withdrawn, leaving a lifting padeye attached to a lifting line which is either connected to a surface vessel or a submersible/diver activated lifting bag or marking buoy package. As a strain is taken on the line the sacrificial cannister is then deformed or destroyed.

Kataoka [6] reported tensile failure loads of 3/4" studs to be about 27,000 lbs. This would make 3/4" single stud lifting padeyes compatible with 7/16" wire rope which has a breaking strength of 12 to 14 tons. Sacrificial cannisters containing single stud lifting padeyes attached to lifting pendents of 10 feet could be fabricated and stored in a vessel's salvage hold.

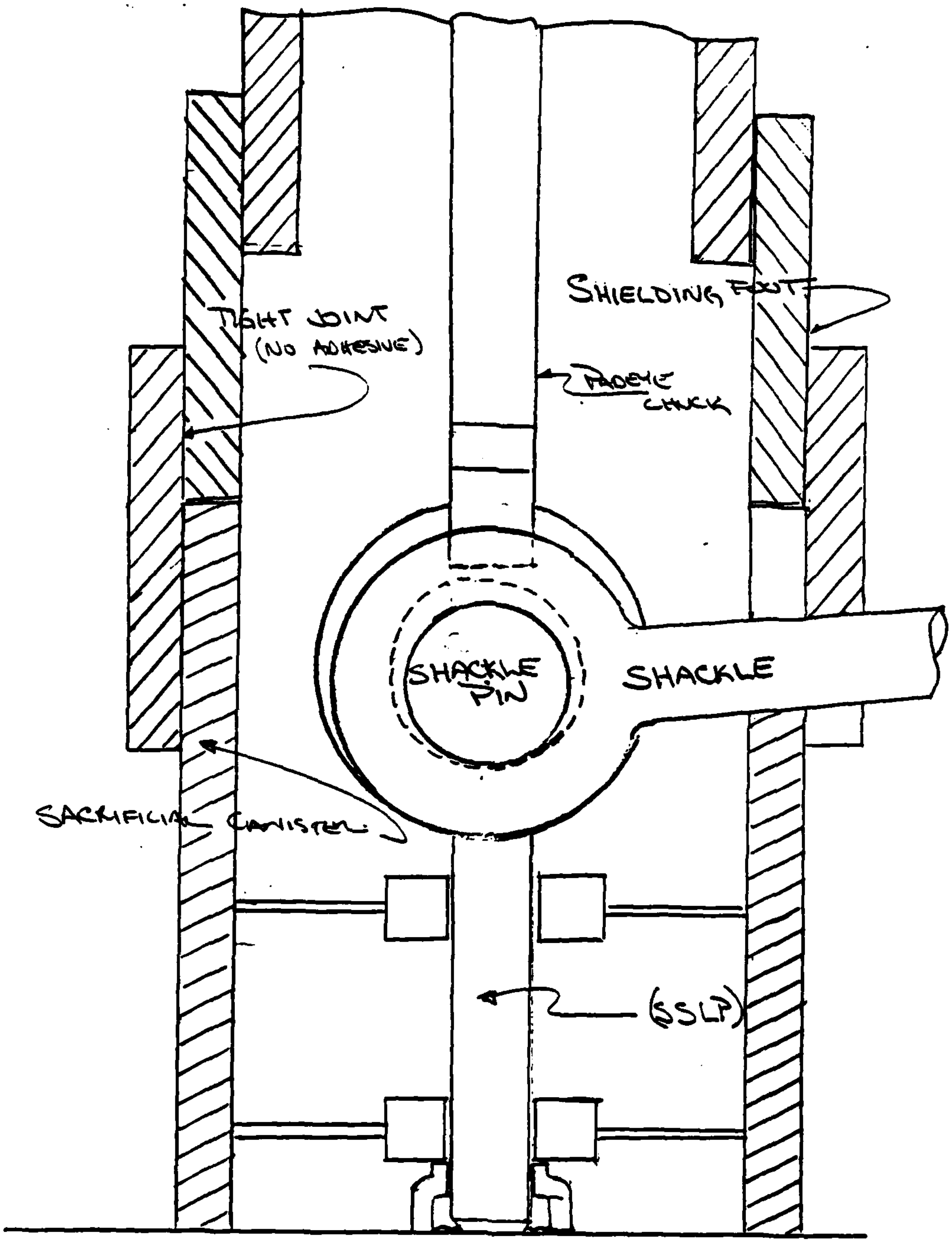


Figure 4.2 SSLP SACRFICIAL CANNISTER

4.3.2 Three Stud Lifting Padeye

As lifting padeyes do not require a gasket, it would be advantageous to have a multiple stud lifting padeye which would not require the use of a template to ensure proper alignment of the studs. Such is the three stud lifting padeye. (Figure 4.3) The first stud is welded to any suitable location. The second stud is welded in any location where the shielding foot can be aligned on the foot. The welding of the third stud is done in a location where the lifting foot is aligned with the first two studs. This approach is advantageous in that it does not require a template which can be lost or misaligned. There is the potential problem in that the outside radius of the shielding foot would not place the studs far enough apart to accomodate the padeye and the nuts required. The proper spacing can be achieved by placing a sleeve around the shielding foot. The three stud lifting padeye (3/4" studs) could be expected to have a breaking strength of 60,000 lbs and could be lifted with 7/8" wire rope. These padeyes could be made up and stored in a vessel's salvage hold as well. The advantages of the three stud lifting padeye are that:

1. It does not require the use of a template.
2. It can be rapidly welded, even in total darkness.
3. After use it can be unbolted and used elsewhere.

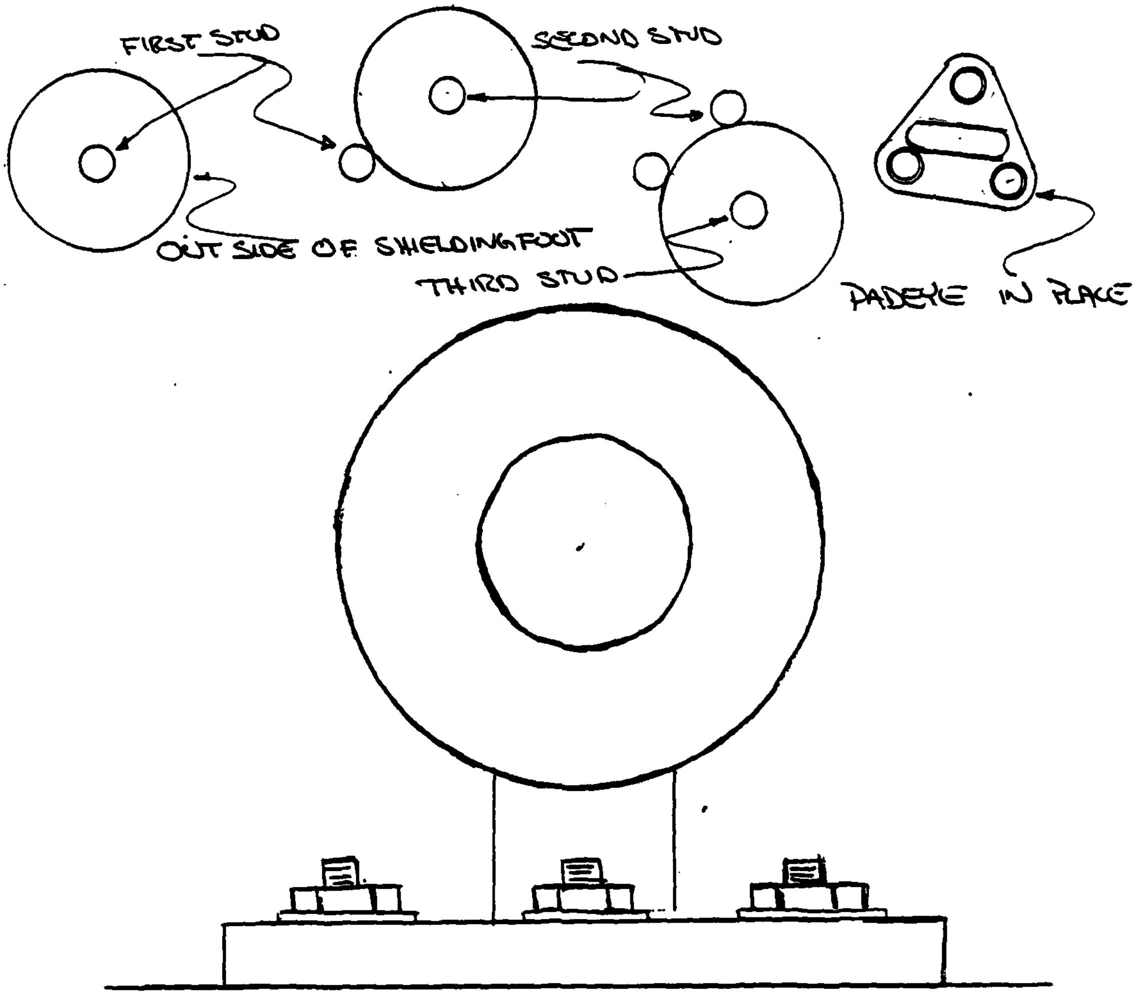


Figure 4.3 THREE STUD LIFTING PADEYE

4.3.3 Multiple Stud Lifting Strap

There are many ways to raise ships from the ocean floor. They may be pumped, and if submerged in shallow water, cofferdams may be required. They can be filled with a type of foam, as foam is both expensive to apply and remove, it has limited applications. If the ship can be made air tight it can be pumped with compressed air to displace the water. Finally, ships can be raised to the surface by lifting craft.

When using lifting craft, slings or lifting chains must be placed under the sunken vessel. This is often difficult as tunneling may be required to pass the lifting member under the sunken ship. This may be avoided by welding lifting padeyes to the sides of the ship. At depths where the quality of SMAW is greatly degraded, the lifting bands should be stud welded to the sides of the ship. Figure 4.4. Using 24 3/4" studs as positioned in Figure 4.4, a lifting strap with an ultimate strength of 100 tons can be constructed. The multiple stud lifting strap with the retaining strap can also withstand a 50 ton lateral force. As the studs are required to be placed very close together, a shielding foot template could not be used. This will require a gasket/template type template, though it will not remain in place after the studs are welded. The application procedure is displayed in Figure 4.5

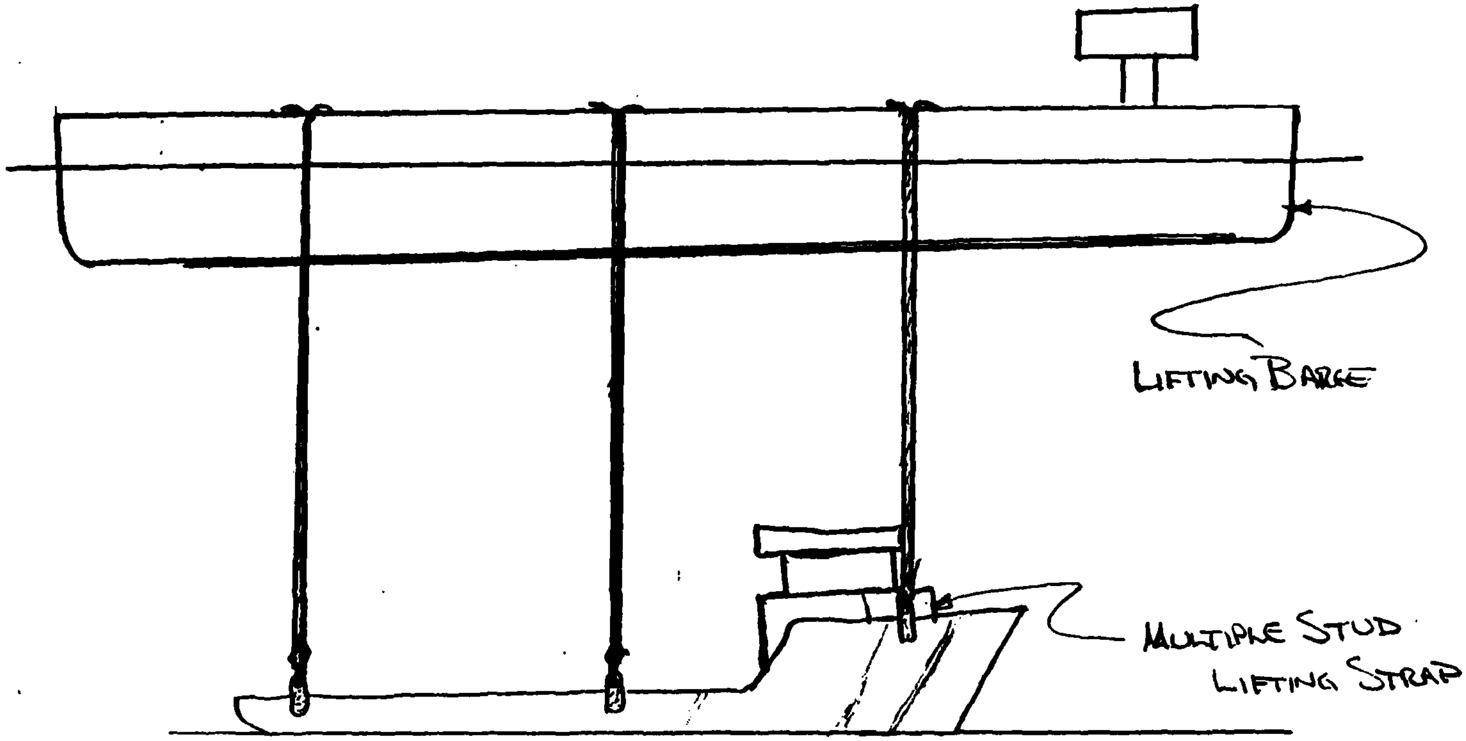


Figure 4.4 MULTIPLE STUD LIFTING STRAPS

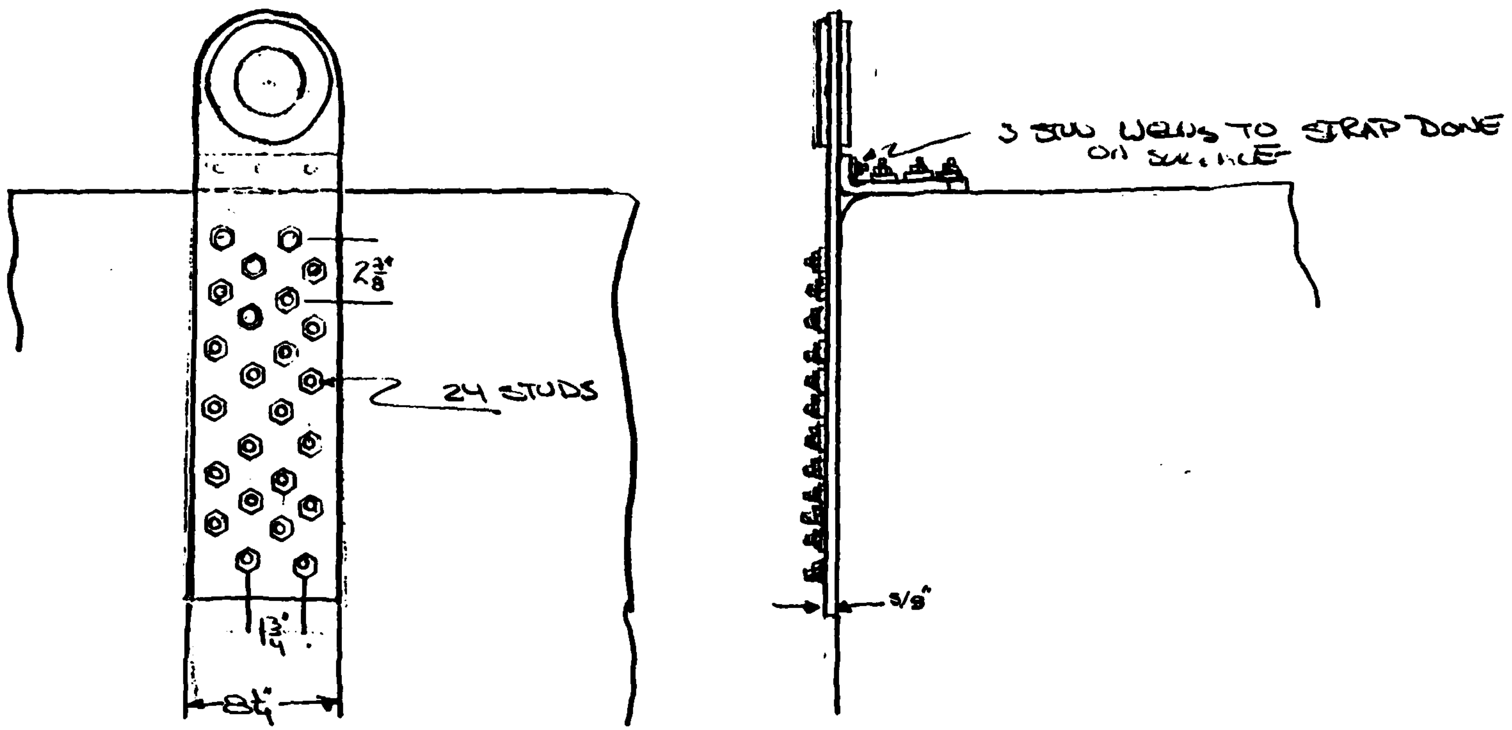


Figure 4.5 MULTIPLE STUD LIFTING PADEYE ARRANGEMENT AS DESIGNED

Such a lifting strap could accomodate up to 4" shackles having a safe working load of 96 tons and use 1 5/8" or 1 3/4" wire rope having breaking strengths of about 100 tons. It is assumed a joint efficiency of 50% can be achieved in such a lifting strap.

4.3.4 Turning Padeye

During salvage operations, wire rope, chains, and other salvage equipment is often required to be moved from one place on a stranded vessel to another. Many times this equipment is dragged across the ship's deck by leading a line around a set of bitts or other deck fittings. Often a turning block is attached to the deck fitting in order to preserve the life of the line. However, many times such a deck fitting is not located in a position that facilitates the desired equipment stationing. In such cases a padeye to which a turning block is shackled is desired.

A turning padeye could be welded (SMAW), but once in place it is extremely difficult to remove. A stud welded turning padeye, using 3/4" studs welded as close together as the shielding foot will allow, will have the same strength as one welded with a 1/4" fillet around its perimeter. (Which could be done to double its mounting strength.) Using 12, 3/4" studs, it would have an ultimate strength of 50 tons, again assuming a 50% joint efficiency. Such a turning padeye will use a 3" shackle and accomodate 3/4" wire rope. Figure 4.6.

Figure 4.7 shows the type of shielding foot template that would be used. Such a template should be made of 3/8" plywood or aluminum and be stored with the padeye in a vessel's salvage hold.

The first two studs are welded in the same fashion as the first two in the three stud lifting padeye. The template is then placed over the first two studs, studs 3-7 are then welded by aligning the shielding foot in the semicircles provided. The template is then rotated about its longitudinal axis and studs 8-12 are welded.

The turning padeye or a smaller but similar fixture could be used to mount the base and tension leg of an A-frame. The ability to use batteries as a power source make this advantageous. The batteries, stud welding equipment and structural members could be loaded by hand from a small boat to a stranded vessel, during sea conditions that prohibit a work boat from remaining alongside, to provide power from a conventional welding machine. The A-frame could then be used to load a conventional welding machine and other salvage equipment aboard the stranded vessel.

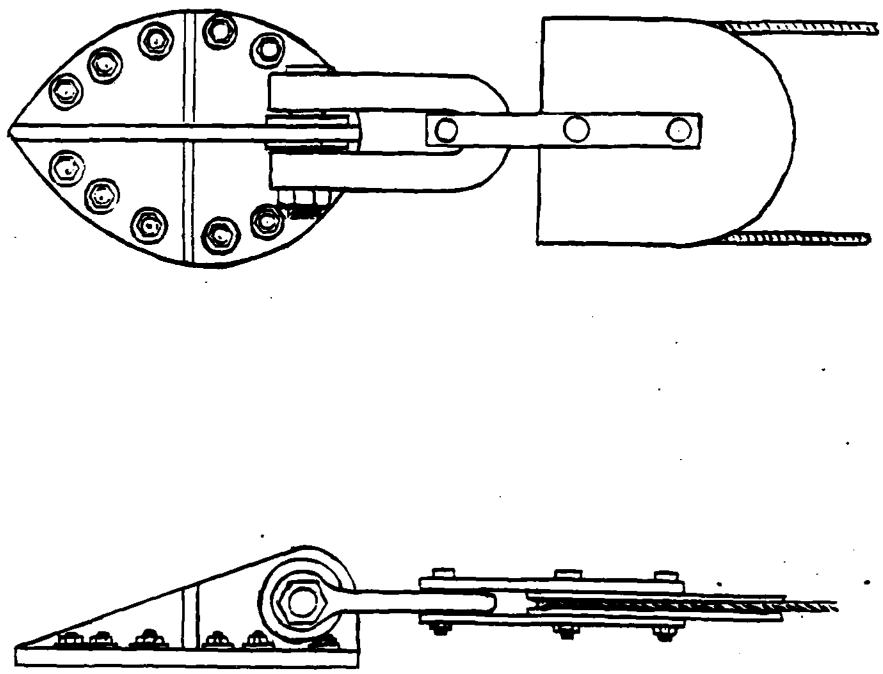
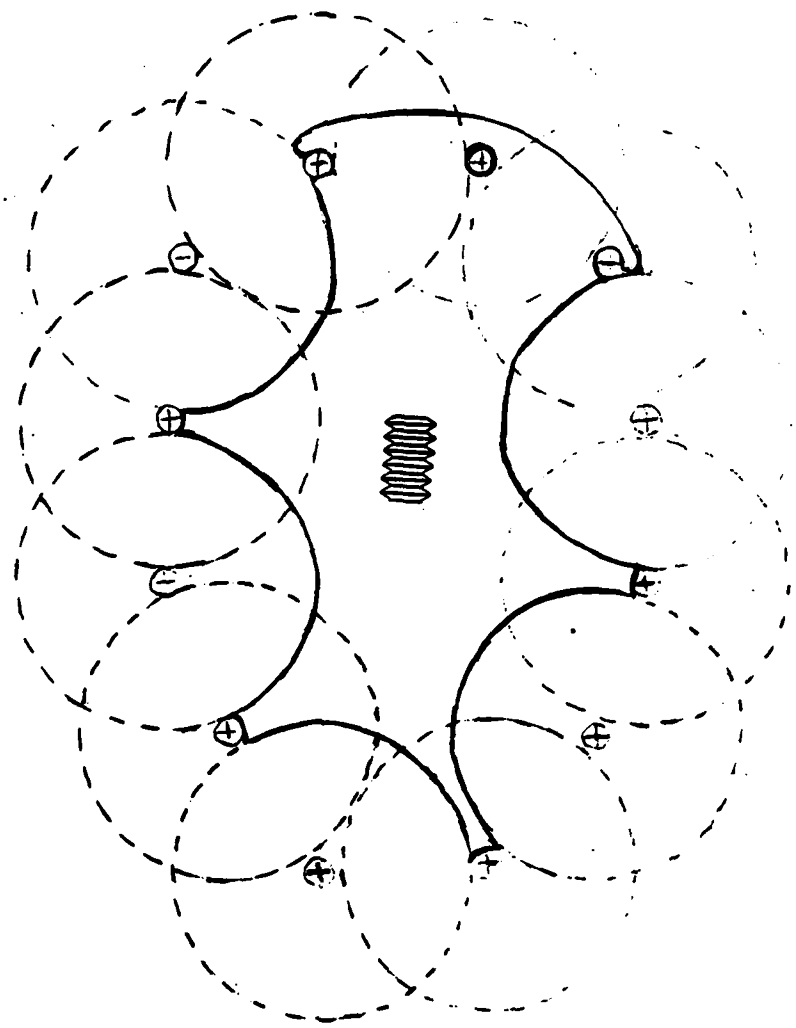


Figure 4.6 STUD WELDED TURNING PADEYE



NOTE: The stud should be of uniform thickness and threaded throughout its length if gasket is to be overlaid for alignment.

Figure 4.7 TURNING PADEYE TEMPLATE

4.4 Jacking Gear

Jacking, Figure 4.8, is used when a vessel is hard aground and its cargo can not be removed to lighten the ship. The 12" x 12" head timbers presently are bolted to the sides of the ship. Bolting requires that holes be cut, and then plugged after the salvage operation. The purpose of these bolts should be served by studs. The application of studs would not only require less time to apply, but would require less time and cost to remove. The same applies to the 6" x 6" angle iron if it were to be stud welded to the sheer strake. Between 7 and 13, 3/4" studs would be required to mount the head timber and angle iron depending upon the load of the jack [13]. A shielding foot template should be used in positioning the studs.

4.5 Cofferdams and Pressure Locks

Figures 4.9 - 4.10 show cofferdam application. Cofferdams are used to keep the seawater fenced back so that the water in a sunken vessel may be pumped out. Cofferdams are much more effective if built over a hatch coaming. As many modern tugs and offshore supply vessels are built with flush hatches, no coaming exist on which to construct a cofferdam. Angle iron members could be stud welded to the deck of such a vessel to provide a hatch coaming on which a cofferdam could effect a water tight seal.

METHOD OF JACKING

NOTE: Center of pressure of Jacking should coincide with center of bottom pressure.

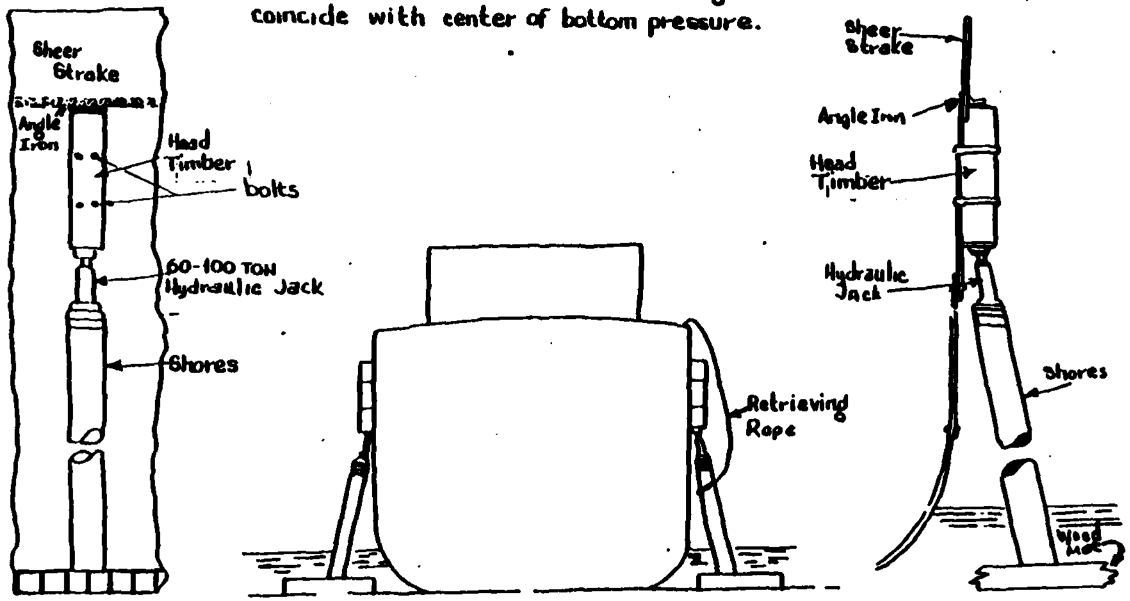


Figure 4.8 JACKING GEAR [13]

WOODEN COFFERDAM FOR SMALL HATCHES

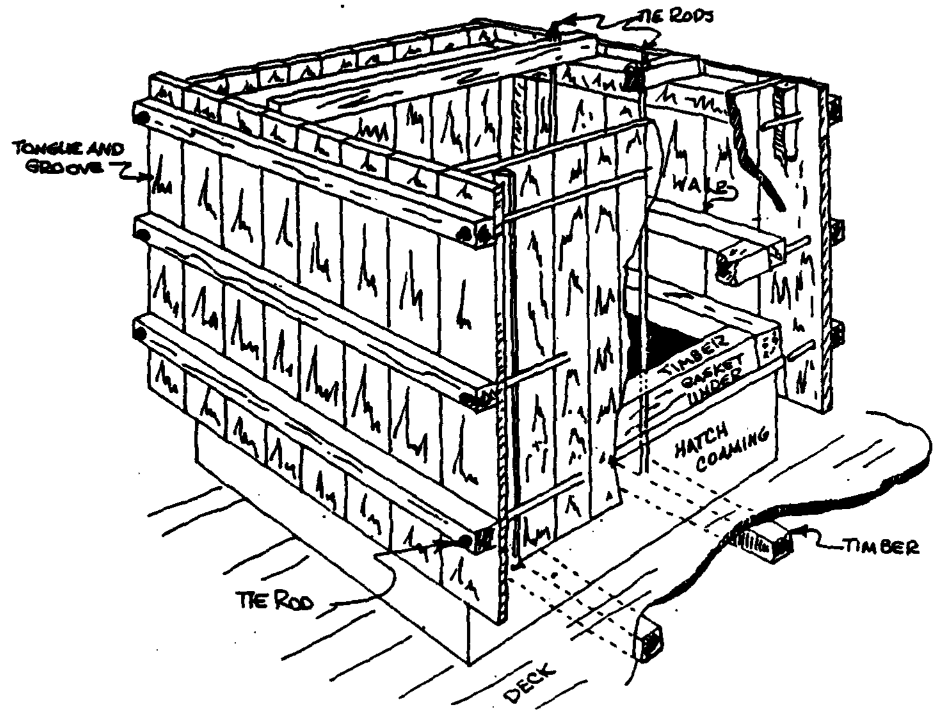


Figure 4.9 SAMPLE COFFERDAM CONSTRUCTION [13]

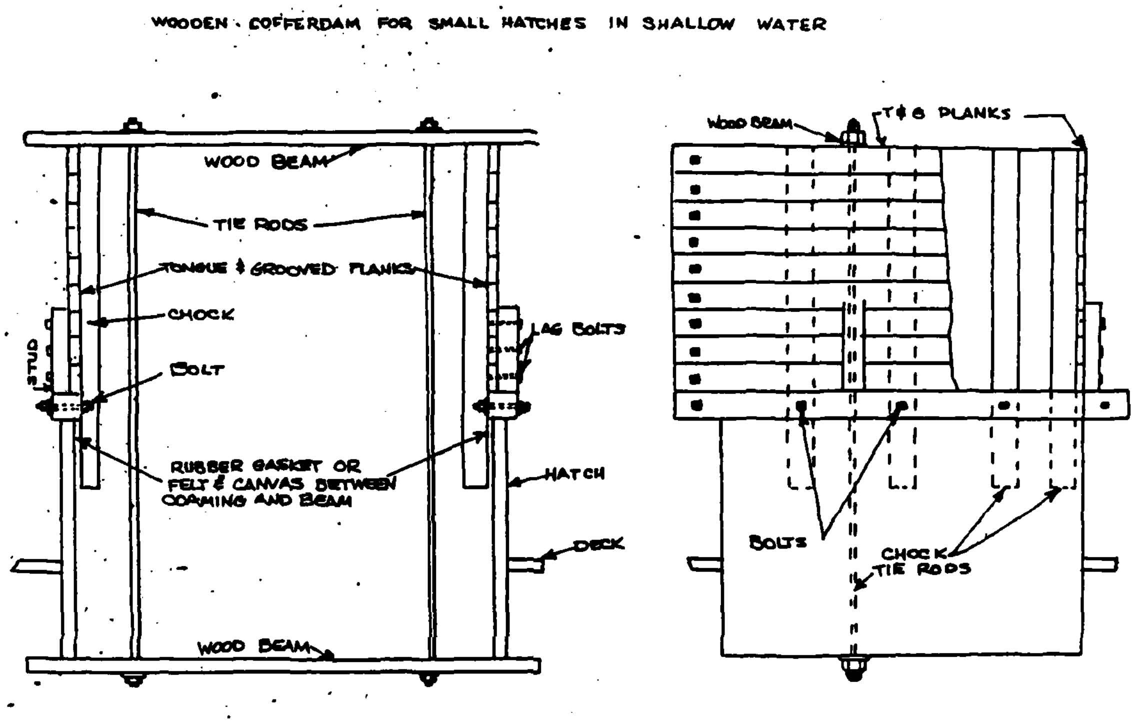


Figure 4.10 SAMPLE COFFERDAM CONSTRUCTION [13]

Pressure locks or air locks are used to gain entrance into a submerged vessel in order to prepare it for dewatering by compressed air [14]. A pressure lock is large enough to accomodate two or three divers. It has hatches at the top and bottom, and is configured with through hull air fittings. The bottom of an air lock is normally welded to the deck of a sunken ship. At depths where SMAW does not provide acceptable results an angle iron assembly, to which a pressure lock can be bolted, should be stud welded. This configuration assembly would be similar to that suggested for cofferdams.

4.6 Hot-Taps

Hot-taps, Figure 4.11, are welded to the side of a stranded or sunken vessel carrying an evironmentally hazardous cargo such as oil. A valve is bolted onto the hot tap flange and a drill bolted onto the valve. The valve is opened, and a hole is then drilled into the fuel or liquid cargo tank of the ship. The drill is backed out, the valve is closed and the drill is then unbolted and exchanged for a hose leading to another vessel where the stranded ship's cargo can be offloaded without damaging the environment.

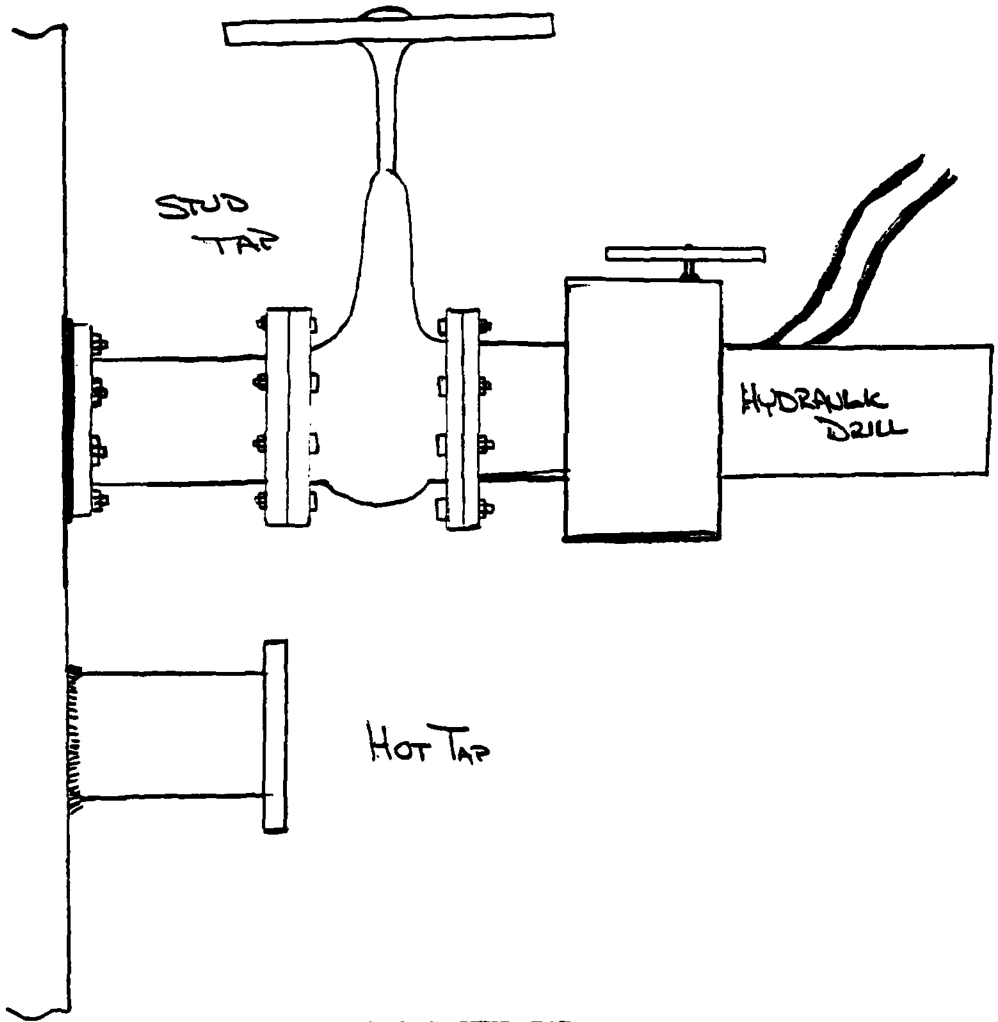


Figure 4.11 HOT TAP & STUD TAP

Hot-taps can also be used to attach hoses leading from air compressors in order to pump air into a sunken or stranded vessel without losing airtight integrity of the compartment to which it is attached.

Once hot-taps have been used, they must be cut off, a patch welded over the hole, and a new bevel must be machined or cut onto the end of the hot-tap. If a hot-tap were to be mounted with studs (stud-tap), it could be used, over and over again, without any machining. A prefabricated circular patch could be bolted over the hole. Stud-taps could be applied by submersibles or saturation divers at great depths where the SMAW process is ineffective. They could either use a template/gasket or a shielding foot gasket if the stud tap is configured with a gasket ring.

A problem is presented for both hot-taps and stud-taps when they are to be welded to a curved surface such as a submarine pipeline. If the pipeline only need be emptied, a hot-tap or stud-tap of much smaller diameter could be used. A smaller device would not see the curvature and the pipe and the areas of poor fitup would be absorbed by the filler metal or gasket.

When hot-taps or stud-taps are required to mate pipes of diameters where the fitup is out of tolerance, a different approach is required. For hot-taps the end must be cut to match the pipe if the fitup is not within 1/8". A stud-tap is advantageous in that by using extremely thick or tapered gaskets fitups as poor as 3/4" could be tolerated. For pipes which do not afford an acceptible fitup, the flange will have to be bent to match the pipe when the stud-tap is fabricated. The holes in the stud-tap flange will also have to be elongated to accomodate the angles at which the studs may be presented. Figure 4.12. Gasket/templates should be used for the mounting of stud-taps to curved surfaces. The interior ply of the gasket/template material should be selected and designed in order to accomodate a low radius of curvature.

4.7 Patching

The most widespread potential use of underwater stud welding is in the field of patching. Repair patches are presently welded (SMAW) or affixed with tee bolts, ell bolts, or explosive driven studs, [14, 15, 16] All the above methods have limitations. Welded patches are of questionable integrity and divers have great difficulty in driving large patches within 1/8" of the sides of the ship. Tee and ell bolts are not bonded to the ship's hull and have the potential of working

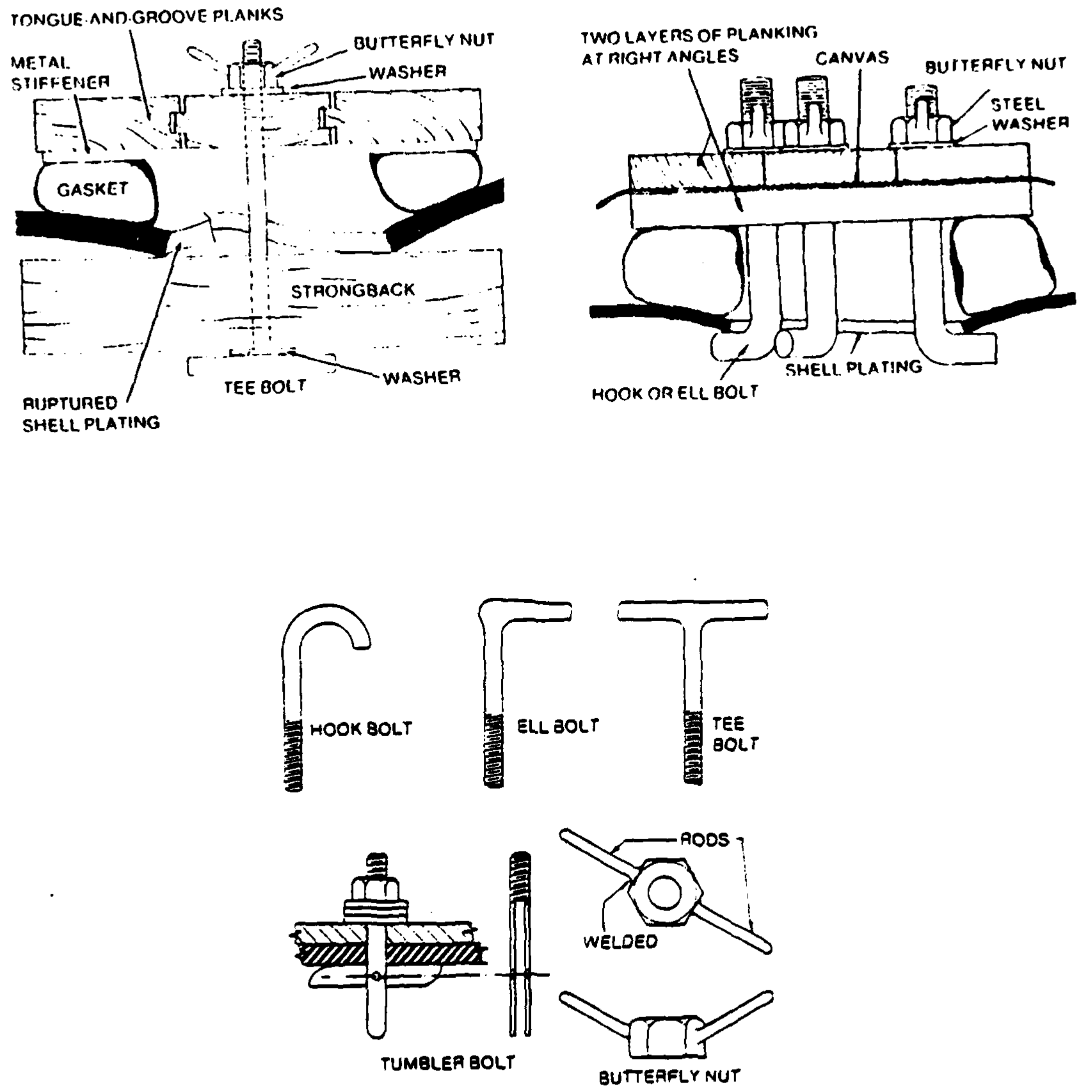


Figure 4.13 SALVAGE FASTENERS AND SMALL PATCHES

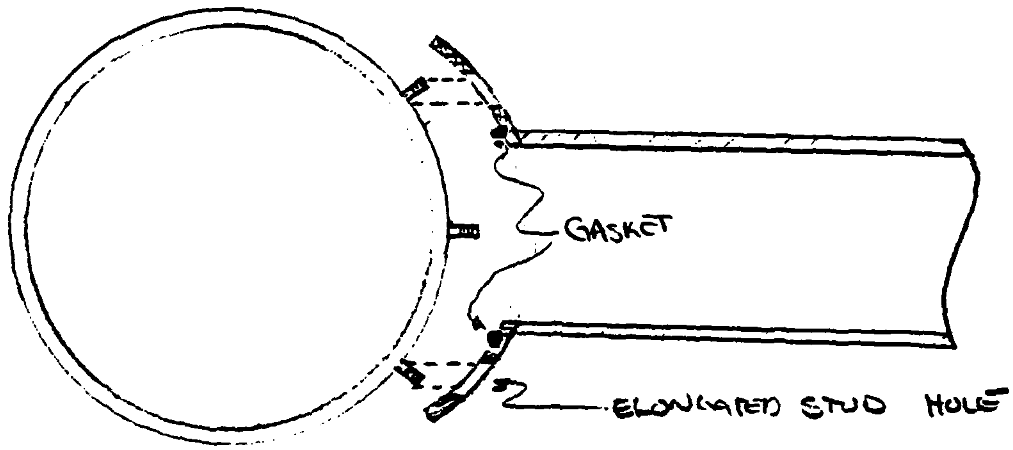


Figure 4.12 ELONGATED HOLES FOR STUD-TAPS TO CURVED SURFACES

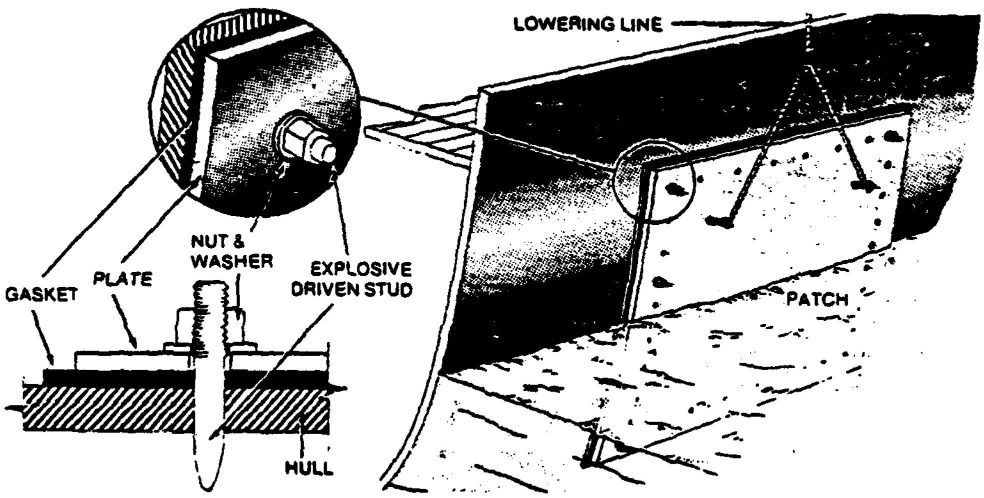


Figure 4.14 PATCHING WITH EXPLOSIVE DRIVEN STUDS

loose. See Figure 4.13. Explosive driven studs, Figure 4.14, can be used to mount large steel patches. These, however, have limited tensile strength and are succeptible to corrosion [17] See Figure 4.15. Explosive driven studs are also limited to a depth of 300 feet [17]. Various patch types and uses of a stud gun will now be addressed.

4.7.1 Plate Patch

Plate patches are presently mounted by explosive driven studs. Stud alignment is of little concern as the studs are either driven into the ship through holes in the patch or through the patch itself. The disruptive nature of explosive driven studs often prohibits their use [17]. They also cannot be used when bending the patch around the turn of the bilge requires tensile forces in excess of the holding power of explosive driven studs.

Patches to be affixed to flat surfaces could be stud welded in place through holes large enough to accomodate the ferrules. Patches to be bent around the turn of a bilge, could be accomplished by first welding the studs positioned by a flexible gasket/template. While fitting the nuts, holes in the plate could be elongated in locations where the studs have been positioned out of tolerance. Plate patches could also be attached by placing the studs and ferrules in holes spaced at

Heavy Duty Solid Studs

Plate Thickness	Average Extraction Force
3/8 in.	8,000 lbs.
1/2	14,000
5/8	16,000
3/4	19,000
7/8	22,000
1	26,000
1 1/8	29,000

Light Duty Solid Studs

1/4 in.	3,000 lbs.
3/8	3,500
1/2	4,000

Figure 4.15 VELOCITY POWER TOOL STUD EXTRACTION FORCES FOR STRUCTURAL STEEL PLATE

one foot intervals around the perimeter of the patch. In either case a stud welded patch, as well as an explosion driven stud patch, is started at the bottom and worked up. This is to allow the lifting line to be used to help turn the patch around curves in the ship's bilge. Even with severe curves in the ship's bilge, once in place and the compartment pumped, a 7' x 10' patch with its center at a depth of 10' will experience a hydrostatic force of 22.4 tons pushing the patch against the side of the ship. This could be done while the patch is being placed to help conform the patch to the sides of the ship.

A 7' wide patch of 1/2" thickness can be bent around the turn of a bilge having a radius of curvature of 2'. This will require a total distributed force of 6 tons to effect the bend and the studs in the turn or the bilge will experience about one ton each, before the compartment is pumped. These forces are about half the working strengths of 3/4" studs (in salvage, a safe working load is equal to 1/6 the breaking strength).

Once pumped, patches will be subject primarily to the forces of shear. A 7' x 10' x 1/2" steel patch weighs about 3/4 of a ton, and the viscous forces of a ship's motion on the patch at 35 knots is about 600 lbs. Both of these forces are well within the safe working load of a single 3/4" stud.

The advantage of using a stud welded patch is that it is semi-permanent. A particular vessel which has suffered minor battle or collision damage would be able to safely carry on its mission for several months without having to be detained in a repair facility. Due to corrosion and other problems explosive driven stud patches are only temporary, if used at all. Conventional (British or American) type patches, roughly diagramed in Figure 4.16, can patch holes at the turn of the bilge. However, due to their lack of strength and severe exposure to the viscous forces resulting from a ship's motion, they are temporary and should only be used on holes too big for plate or plank by plank patches.

4.7.2 Plank by Plank Patch

Plank by plank patches are used to patch holes too large for plate patches. They require minimum surface preparation and maximum work by the diver. A plank by plank patch is diagramed in Figure 4.17.

The angle irons and steel channels attached with arc welded studs can be pulled to the sides of the hull more quickly than those attached using wedges and welded (SMAW) jigs. The steel structures can then be welded (SMAW) to the hull of the ship. The planks can be affixed to the steel channels by arc welded studs. A stud requires only one diver to fit each nut, whereas a bolt requires an additional diver on the opposite side to keep the bolt from turning.

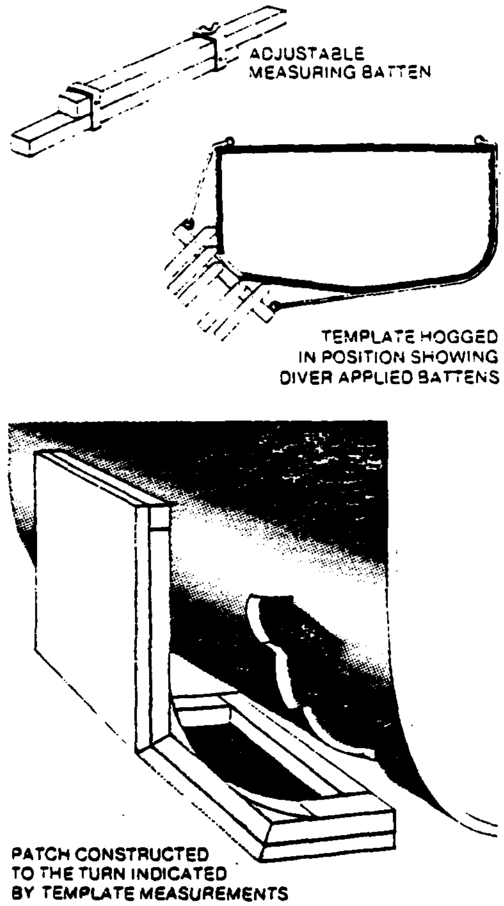


FIG. 1-1 HOLE MEASURING DEVICES

Figure 4.16 LARGE PATCHES

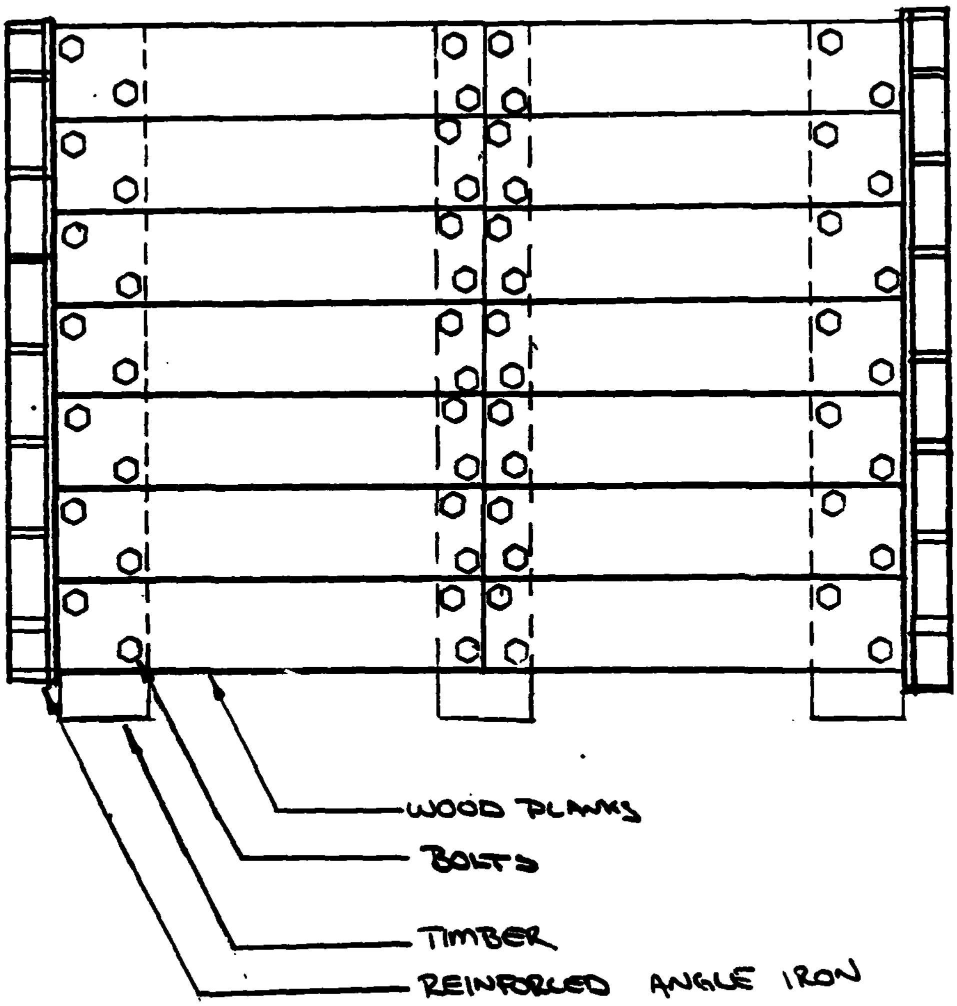


Figure 4.17 PLANK BY PLANK PATCH

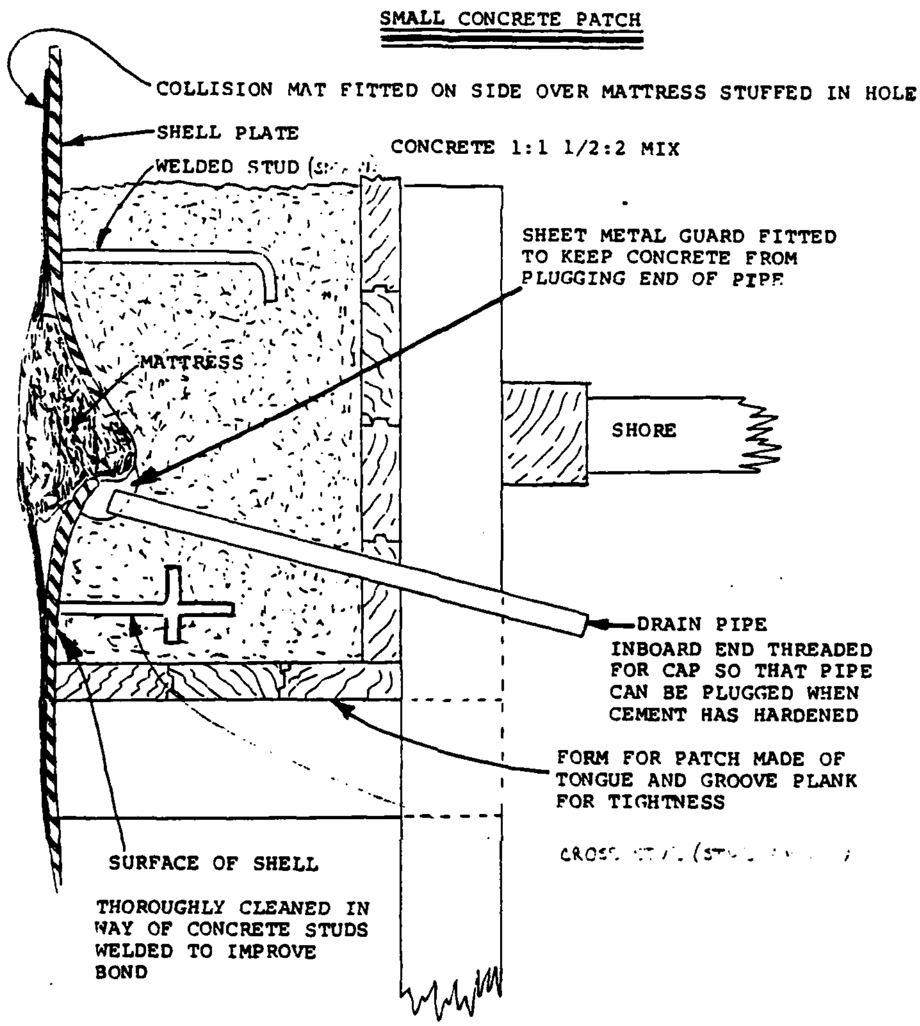


Figure 4.19 STUD WELDED CROSS STUD & A CONCRETE PATCH [13]

4.7.3 Small Patches

Small patches, as displayed in Figure 4.13 have a large frontal area relative to their diameter. This causes considerable drag when underway and may cause the patch to work lose. These patches also require an additional diver inside the ship. Small plate patches as described in 4.7.1 could be applied by a single diver, in less time, and would have a semi permanent status.

4.7.4 Inside Patch

It is possible that a small patch may be required on the inside of a ship's hull if the area outside is not accessible due to the position of the ship resting on the bottom or if the ship is to be blown with compressed air. Due to the exceptional tensile strengths of stud welds, a stud welded patch would be able to safely resist the hydrostatic forces of outside water pressure. The inside patch diagramed in Figure 4.18 would be able to safely patch a hole of seven square feet at a depth of 30 feet. In addition to requiring an additional diver, once refloated, a permanent or semi-permanent patch can be placed outside the ship as there are no protrusions as in other types of mechanically fastened patches. The stud welded strong back would not require templates as the elongated holes would accomodate diver error.

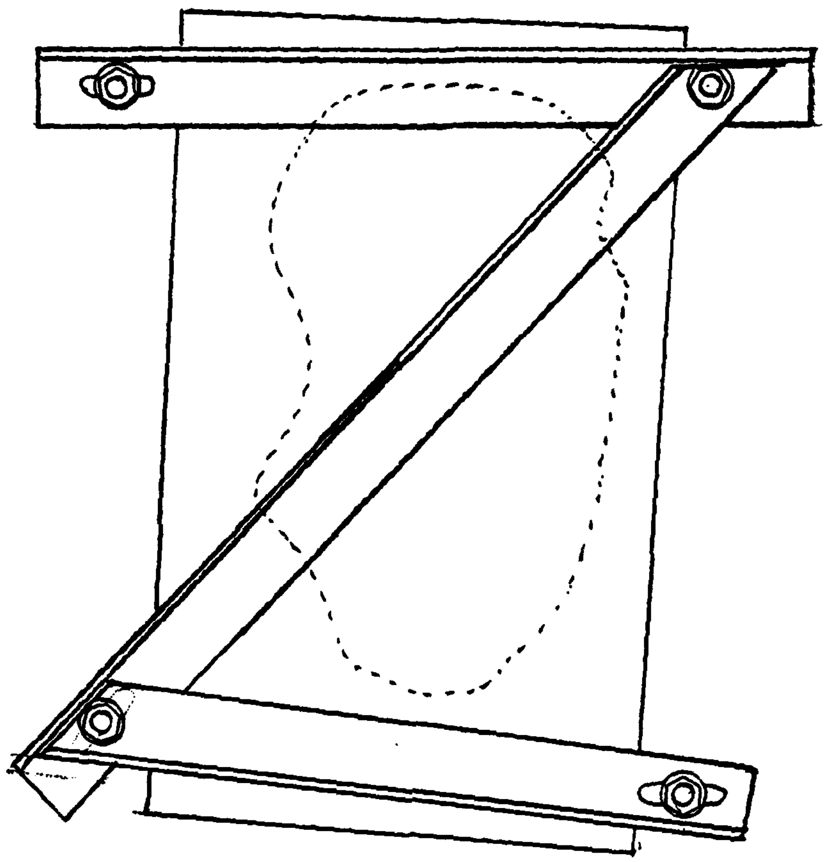


Figure 4.18 INSIDE PATCH

4.7.5 J Studs

When fabricating concrete patches, Figure 4.19, J studs are required to reinforce and hold the concrete in place. Though requiring a shielding foot extension, cross studs could be placed by an underwater stud welding gun. This would produce stronger studs and require much less time than if done by SMAW.

4.8 Shoring and Hatch Jigs

In salvage as well as in damage control, bulkheads, hatches, scuttles and water tight doors often need to be shored. This is to reinforce weakened structures or to secure leaking doors and hatches.

4.8.1 Shoring

Typical arrangements of shoring are displayed in Figures 4.20 and 4.21. Notice the K-shores use the union of the deck and hatch coaming as its lower foundation. Hatch coamings are not always available in convenient locations. If a hatch coaming was not available in Figure 4.20, member "c" would have to run across the compartment to the opposite bulkhead.

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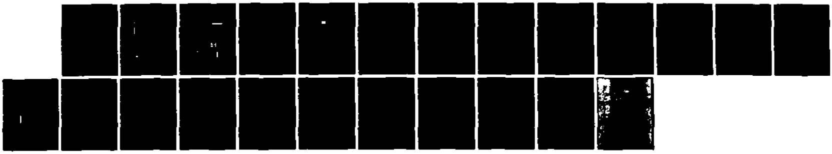

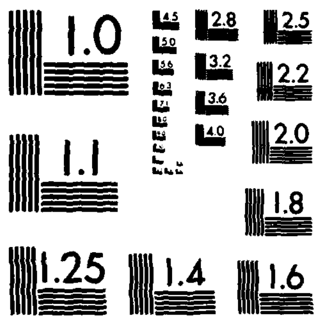
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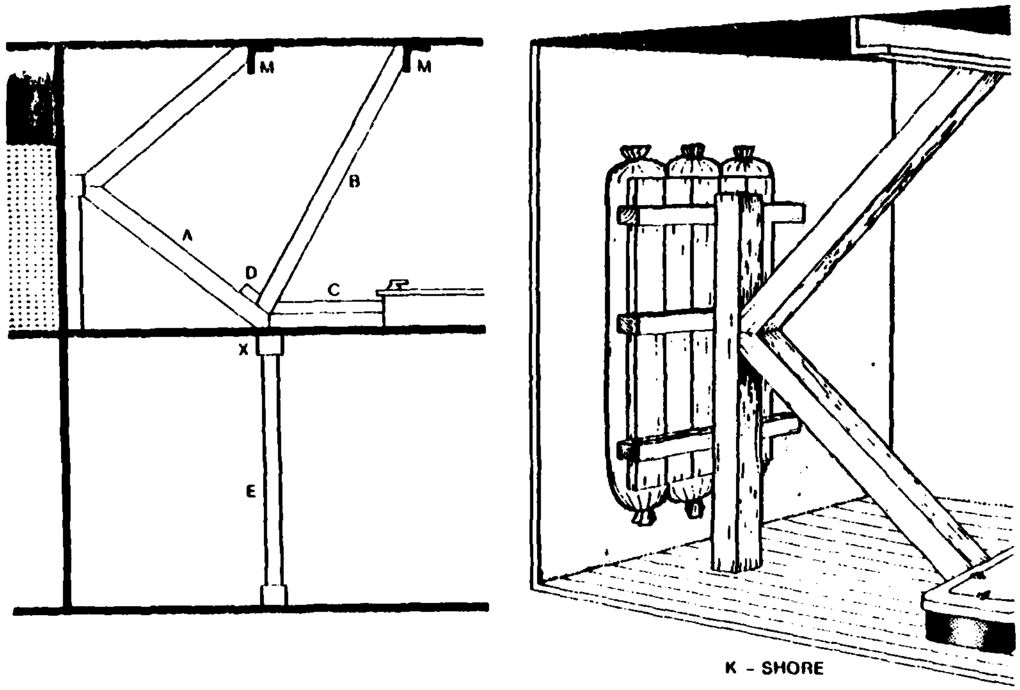


Figure 4.20 SHORING [15]

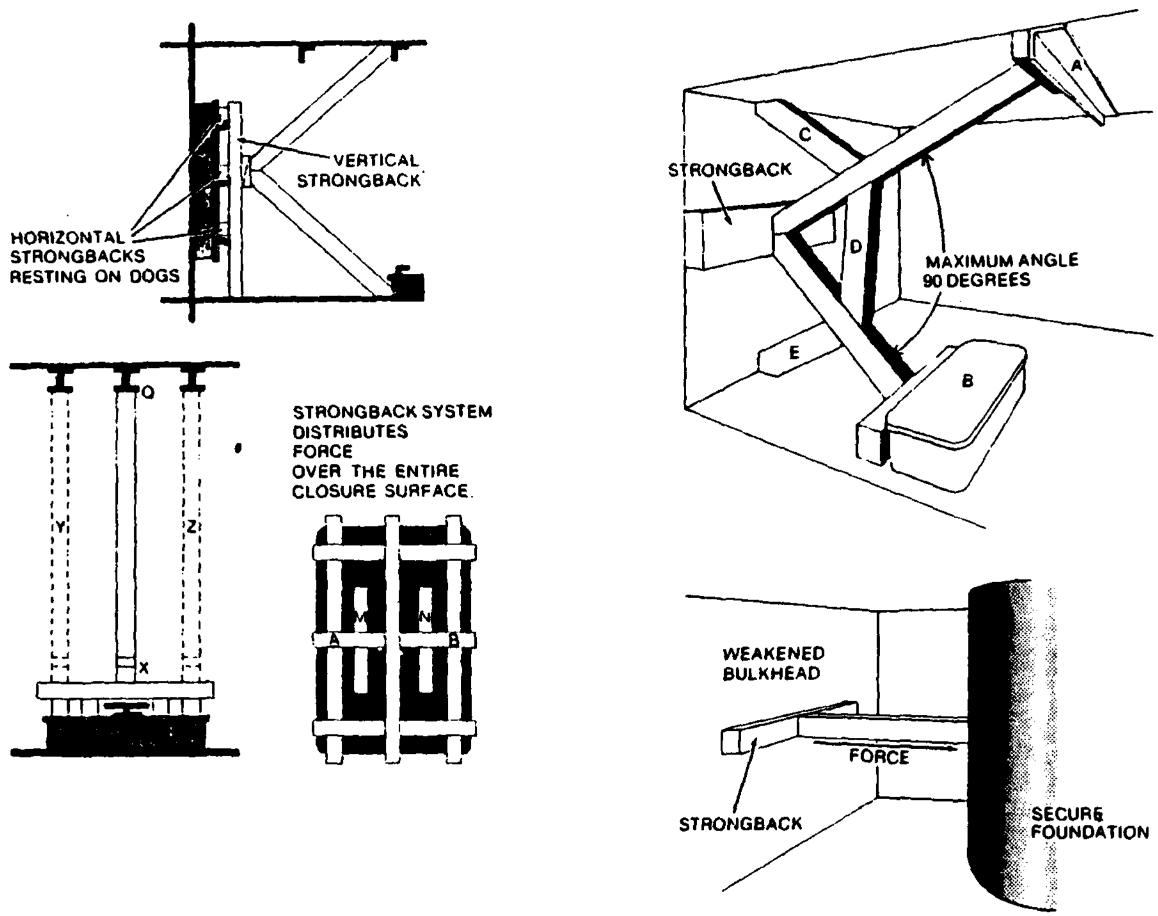


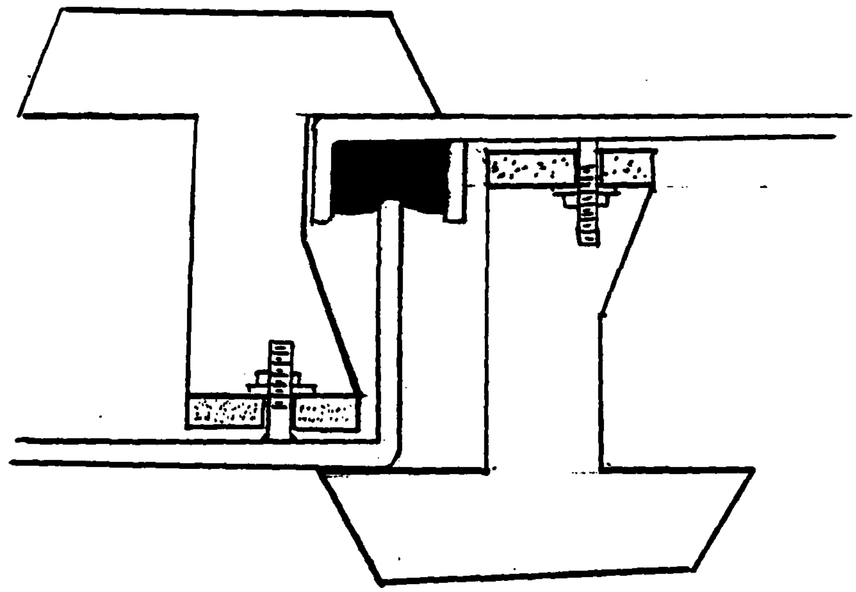
Figure 4.21 SHORING [15]

To serve as a foundation, like a hatch coaming, angle irons could be stud welded to the deck. The 4" x 4" angle irons would not require a template if one end was cut to conform to the shielding foot of the stud gun. The holes of the angle iron could then be aligned over each progressive stud. Use of such an angle brace would require little time and conserve shoring materials. This is also advantageous in that it would be unsafe and nearly impossible to weld (SMAW) such an angle iron in a flooding compartment. The stud gun operator would only require rubber gloves and boots.

4.8.2 Hatch Jigs

Figure 4.21 shows how leaking hatches and water tight doors are shored. The same hatches and water tight doors can be pulled shut by use of a door jig, Figure 4.22. The advantages of a door jig are that:

1. It can be used on both the inside and outside of a watertight door or hatch.
2. It requires only one or two to secure a leaking door or scuttle.(As opposed to a shoring team).
3. A leaking door or hatch can be secured in less time. (As opposed to shoring.)
4. Door jigs do not require shoring material (Conserving it for use elsewhere.)



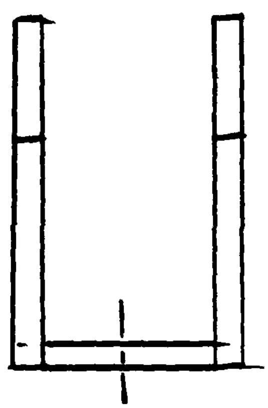


Figure 4.22 HATCH JIG APPLIED TO EITHER INSIDE OR OUTSIDE OF DOOR OR SCUTTLE

Four hatch jigs can withstand the hydrostatic force of 17 feet of sea water on a standard water tight door, at 1/2 of their ultimate tensile strength. Hatch jigs can easily be prefabricated and stored in damage control lockers or along with shoring materials.

4.9 Anode Replacement

Sacrificial anodes made of zinc or aluminum are used to protect ships, pipelines and offshore platforms from corrosion in a salt water environment. The anodes have to be replaced periodically as they corrode. They also have to be replaced when they are dislodged. They are either welded in place (offshore platform) or affixed to studs (ships and pipelines). Often disloged when the mounting studs are sheared off.

4.9.1 Offshore Structure Anode Replacement

Sacrificial anodes are often mounted to offshore structures by means of a web (Figure 4.23). The web holds the anodes at a distance from the structure to provide more effective protection. Replacement anodes (Figure 4.23) can be affixed by brackets to stud welded studs.

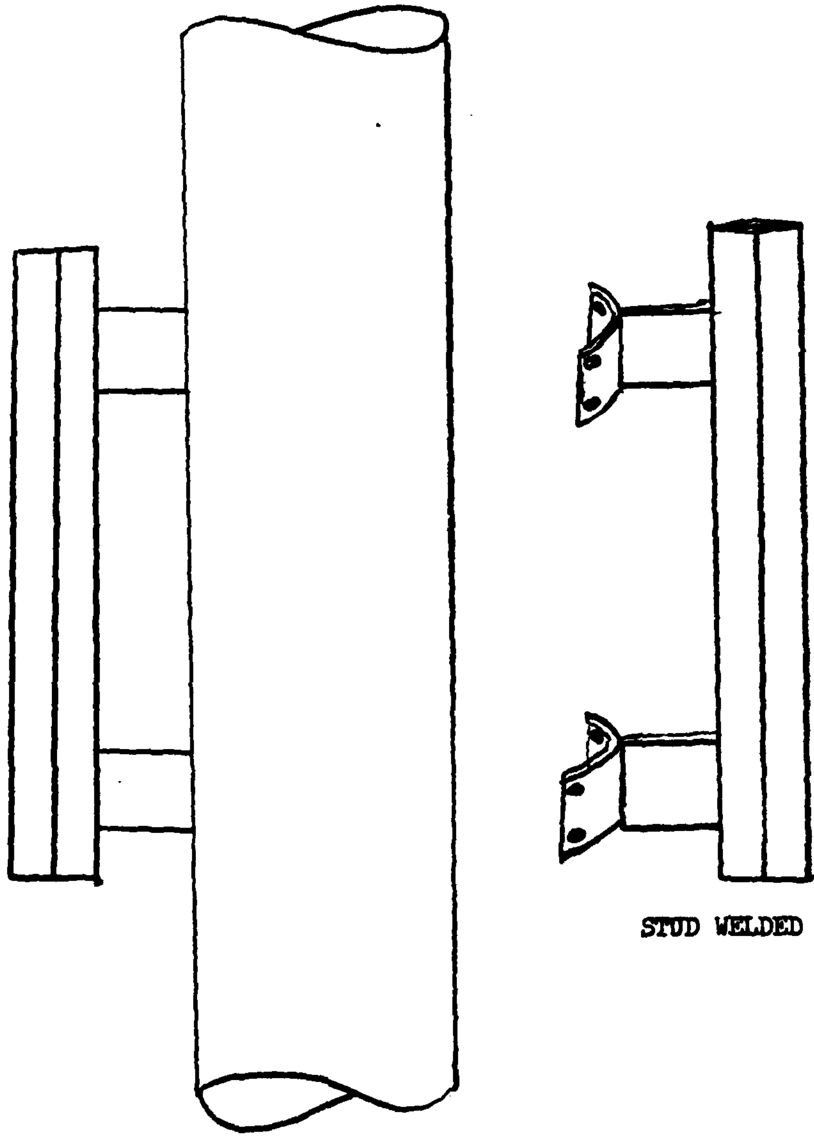


Figure 4.23 ANODE REPLACEMENT

An anode mounted by 2, 4 stud brackets, could have a wet weight of 11 tons if 3/4" studs are used. Two shielding foot templates held by a spacing rod would ensure a proper fitup.

4.9.2 Ship Anodes

Ship anodes can easily be mounted by two studs. The safe shear and tensile loads of 1/4" studs far exceed any expected load. However, as 3/4" studs and nuts are easier for divers to work with, they should be used.

Chapter 5

Test and Evaluation

5.1 Introduction

In this chapter a method of testing and evaluating selected underwater and surface stud welding tasks will be presented. As it would be difficult to perform and evaluate all the tasks required, only selected tasks have been chosen.

5.2 Testing and Evaluation

Of the 18 feasible tasks (Figure 5.1) 7 have been chosen for field testing and evaluation.

Single Stud Padeye*
3 Stud Padeye*
Multiple Liftiing Strap*
Plate Hot-Tap
Plate Patch
Small Patch
Hatch Jig
Ship Anode Replacement

* Failure strengths determined by destructive testing in the Laboratory.

	MANUAL	TELE-MANIPULATOR	PACKAGE
SINGLE STUD PAD EYE	+	+	+
3 STUD PAD EYE	+	+	+*
MULTIPLE STUD LIFTING STRAP	+	+	0
TURNING PAD EYE & A-FRAME	+		
JACKING GEAR	+		
COFFERDAM	+		
PRESSURE LOCK	+		
PLATE HOT-TAP	+	+	+*
PIPE HOT-TAP	+	+	0
PLATE PATCH	+	+	0
PLANK BY PLANK PATCH	+		
SMALL PATCH	+	+	+*
INSIDE PATCH	+		
J STUD (CONCRETE PATCH)	+		
ANGLE BRACE (SHORING)	+		
HATCH JIG	+		
OFFSHORE STRUCTURE ZINC REPLACEMENT	+	+	+*
SHIP ZINC REPLACEMENT	+		

+) CAPABLE

+*) CAPABLE/ REQUIRES MANIPULATOR TO FIT NUTS

0) NOT CAPABLE

BLANK) NOT A DESIRED TASK OF SYSTEM

Figure 5.1 CAPABILITIES OF UNDERWATER STUD WELDING

Task performances can be evaluated by using the following formula.

$$P = \frac{TA \times SS \times DC}{TS \times SA}$$

Where:

TA = Time to complete an alternative task*

TS = Time to complete stud welded task*

SA = Ultimate strength of alternative assembly

SS = Ultimate strength of stud welded assembly

DC = Diver comments**

P = Performance

* Number of men required (including topside personnel) times the total time from the first diver enters the water until decompression is complete if required.

** DC = 1.5 if studs preferred
1.0 if no preference
0.5 if studs not preferred.

5.2.1 Padeyes

Conditions for welding the single stud padeye (SSPE), three stud padeye (3SPE), and multiple stud lifting strap (MSLS) are as follows:

	SSPE	3SPE	MSLS
Depth	100'	100'	50'
Visibility	Ambient	Total Darkness	Clear

If the performance (P) is greater than one, stud welding is the preferred method. The formula needs to be modified slightly for each task. The variations of the formula and the conditions under which the tasks are to be performed will now be discussed.

5.2.2 Padeye Evaluation

The single stud padeye (SSPE), the three stud padeye (3SPE) and the multiple stud lifting strap (MSLS) tasks should be performed by divers under the following conditions.

	SSPE	3SPE	MSLS
Depth	30' 100'	30' 100'	30'
Visibility	Ambient	Total Darkness	Good

The SSPE and 3SPE can be evaluated by experimentally determining their failure strengths, as they are not compared to other processes. The MSLS can be evaluated by application of the performance formula.

5.2.3 Hot-Tap Evaluation

Hot-Tap performance can be evaluated by attaching a test piece (Figure 5.2) to a flat plate under the following conditions:

	Stud-Taps	Hot-Taps
Depth	30'	30'
	100'	100'
Visibility	Good	Good

In evaluating the performance factor, the welded piece should be welded until it holds 100 PSIG. The stud-tap test speciman should be evaluated likewise. The performance formula should be entered with SA = 100 and SS equal to 100 or a lower pressure if 100 is not achieved.

5.2.4 Patch Evaluation

The stud welded patch should be evaluated by fixing a 7" x 10" patch around the turn of the bilge amidships, of a large naval auxillary vessel. For a period of 6 months, it can be evaluated for leakage by a system similar to the one indicated in Figure 5.3. The valve can be used for determining the rate at which the patch leaks over its service life thereby serving as a method of evaluation.

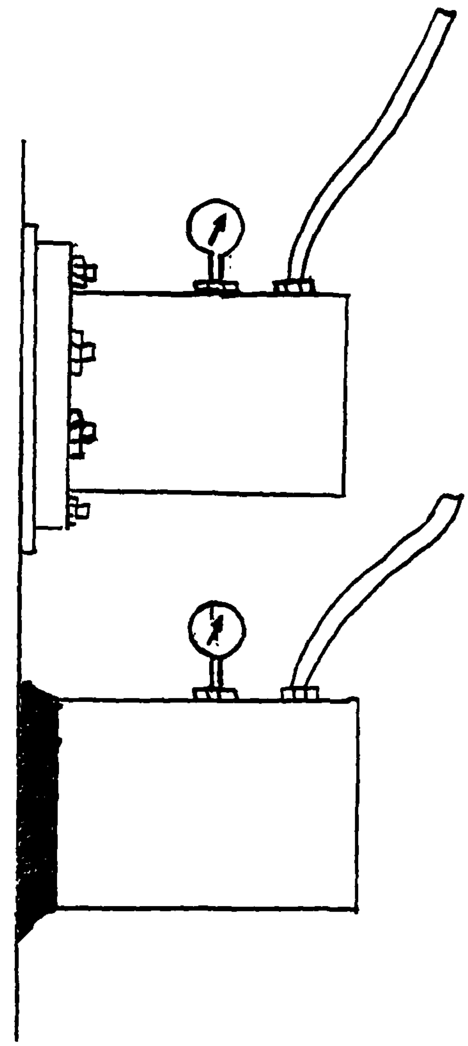


Figure 5.2 STUD TAP EVALUATION

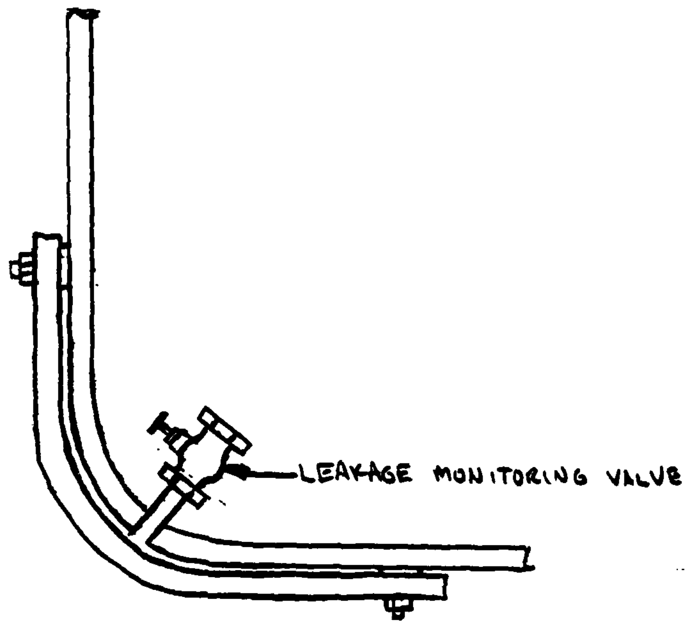


Figure 5.3 STUD WELDED PLATE PATCH EVALUATION

The stud welded plate patch can be evaluated against a welded (SMAW) and explosion driven stud patch by comparing man-hours required. Large (7' x 10') and small (2' x 2') patches should be compared. All strengths should be assumed to be 1. The patches should be fitted underwater on a hull section with the curvature indicated in Figure 5.4.

5.2.5 Damage Control

The damage control performance can be evaluated by simply comparing performance times. Time may be used as it is weighted by the number of men required to accomplish a given task.

Water tight doors with a 3/4 inch gap should be shored water tight against a rising head of seawater. The head should rise from the foot of the door at a rate of 2 feet per minute. The shoring man-hours required should be compared to hatch jig man-hours required to effect a water tight seal. (Figure 5.5)

5.2.6 Anode Replacement

In order to evaluate ship anode replacement performance, selected anodes should be affixed with underwater welded studs. This should be done at a time when the test vessel leaves a dry dock. Thus the endurance of the stud welded anodes can be compared with that of the anodes mounted on dry

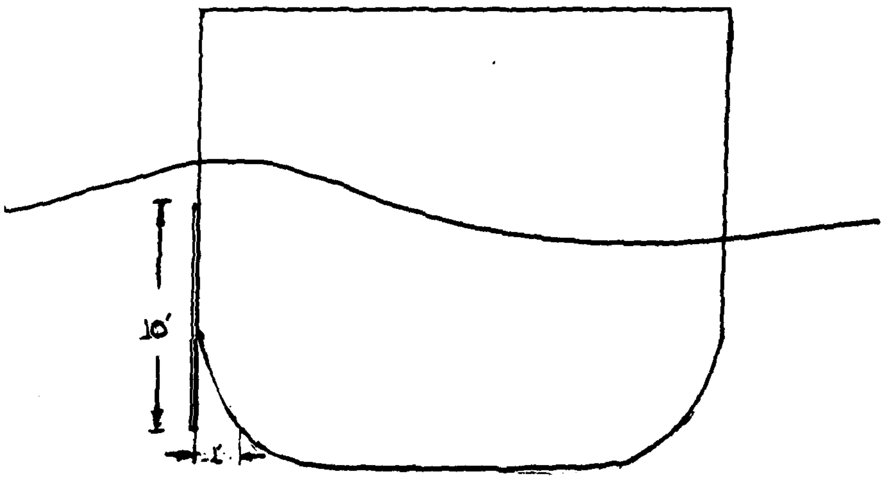


Figure 5.4 STUD WELDED PLATE PATCH EVALUATION

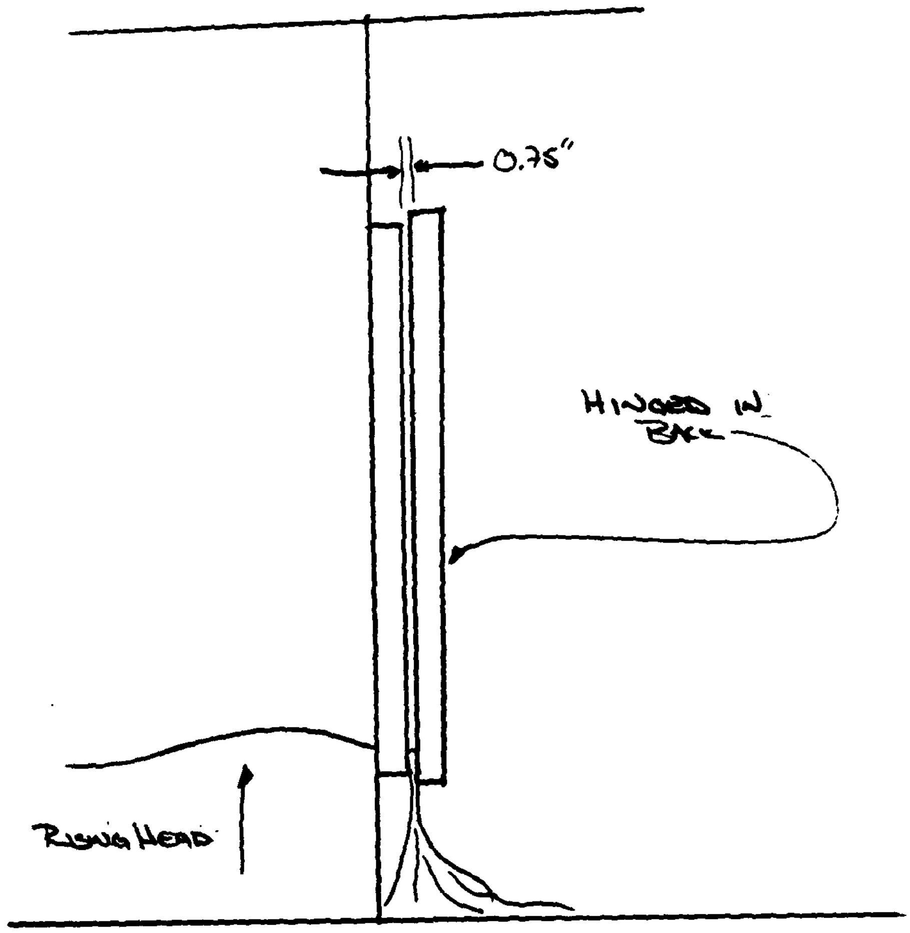


Figure 5.5 HATCH JIG EVALUATION

dock. The diver placed anodes will not be expected to survive as long as the shipyard mounted anodes. However, the relative life of stud welded anodes can be determined.

5.3 Test Locations

The selected test tasks would be undertaken by a myriad of interested bodies. The Naval Experimental Diving Unit (NEDU) could perform these tasks. However, it would be best to perform the aformentioned tasks under the most "real" of conditions.

Mobile Diving and Salvage Unit (MDSU II) located in Little Creek, Virginia, is capable of undertaking this feat. As all the U.S. Naval Atlantic Salvage Assets undergo salvage training/evaluation annually under the observation of MDSU II, a large number of tests could be performed. The pieces requiring destructive testing could be returned to M.I.T for evaluation, along with comments on the gun,s handling performance.

Chapter 6

Conclusion

6.1 Conclusion

During the course of this study, it has been determined that a great number of tasks can be feasibly undertaken by the M.I.T. underwater stud welding gun. A means of evaluating the author's hypothesis, that underwater stud welding can perform tasks of equal or superior strength in equal or less time than alternative methods, has been provided.

The missions described all take place in a marine environment. The author wonders how long before these or similar tasks will be required to be accomplished in outerspace? The shielded stud welding process provides conditions that should allow the initiation of an arc in a vacuum. As such further study should be undertaken in this field.

6.2 Recommendations

The following subjects are recommended for study in order to improve the M.I.T. stud welding gun.

1. Buoyancy Compensation - this should have a system by which the gun will remain naturally bouyant in order to facilitate easier usage.

2. Shielding Foot - the shielding foot should be modified in order to accomodate a variety of work pieces, this could be done by use of a wire brush nozzle, a spring loaded foot or both.

3. Stud Loading - loading studs by hand, or by telemanipulative techniques absorbs a great portion of the time required to complete a particular task. In addition it often complicates the process. As there presently exist stud guns which can be reloaded automatically by air pressure, a study should be undertaken to design a seawater hydraulic stud reloading system.

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